END

FILMED

DTIC

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMPRESSIVE STRENGTH OF EPOXY RESIN CHOCKS

SUBJECTED TO ELEVATED TEMPERATURES

by

Richard Paul Prince

September 1984

Thesis Advisor: D. Salinas

DTIC
ELECTE
APR 4 1985

85 03 18 002

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. A152 018	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Compressive Strength of Epoxy Resin Chocks Subjected to Elevated Temperatures	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1984
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard P. Prince	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943	12. REPORT DATE September 1984
	13. NUMBER OF PAGES 74
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Epoxy Resin Chocks
CHOCKFAST ORANGE
Epoxy Chock Elevated Temperature Exposure
Temperature Exposure of Epoxy Resin Chocks

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Epoxy resin chock specimens were molded from Philadelphia Resins Corporation's product CHOCKFAST ORANGE. The 2" x 2" x 1 1/4" chocks were divided into seven groups of 12 specimens each and subjected to the temperature environments of $21.5°C$, $40°C$, $80°C$, $100°C$, $120°C$, $160°C$, and $200°C$ respectively. A single furnace was used to create the proper environment for each elevated temperature group and equal amounts of

DD FORM 1473 $_{1\,JAN\,73}$ EDITION OF 1 NOV 65 IS OBSOLETE

S N 0102-LF-014-6601

20. (Continued)

specimens were removed at regular intervals up to a 120 hour maximum exposure. The specimens were allowed to cool to ambient conditions and then were placed under compressive loading. Stress versus strain plots revealed increased ultimate compressive strengths but decreased moduli of elasticity for each elevated temperature group.

Compressive Strength of Epoxy Resin Chocks
Subjected to Elevated Temperatures

by

Richard P. Prince
Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1984

Author: _____
Richard P. Prince

Approved by: _____
David Salinas, Thesis Advisor

_____
Paul Marto, Chairman
Department of Mechanical Engineering

_____
John Dyer, Dean of Science and Engineering

3

ABSTRACT

Epoxy resin chock specimens were molded from Philadelphia Resins Corporation's product CHOCKFAST ORANGE. The 2" x 2" x 1 1/4" chocks were divided into seven groups of 12 specimens each and subjected to the temperature environments of $21.5^{\circ}C$, $40^{\circ}C$, $80^{\circ}C$, $100^{\circ}C$, $120^{\circ}C$, $160^{\circ}C$, and $200^{\circ}C$ respectively. A single furnace was used to create the proper environment for each elevated temperature group and equal amounts of specimens were removed at regular intervals up to a 120 hour maximum exposure. The specimens were allowed to cool to ambient conditions and then were placed under compressive loading. Stress versus strain plots revealed increased ultimate compressive strengths but decreased moduli of elasticity for each elevated temperature group.

4

TABLE OF CONTENTS

LIST OF FIGURES

7

I. INTRODUCTION

The objective of this experimental program was to acquire information on the compression loading characteristics of epoxy resin chocks having been subjected to various elevated temperature environments. This information is to be used by the Navy in officially certifying the use of epoxy chocks in the installation of primary and auxiliary machinery and weapons systems aboard Navy ships and submarines. Additionally, the results generated will also be used by NAVSEA in the development of an epoxy chock installation manual.

The most popular and widely used epoxy chock product in industry to date has been CHOCKFAST ORANGE, manufactured by Philadelphia Resins Corporation of Montgomeryville, Pennsylvania. Although there exists several other epoxy chock products manufactured by different companies, none of these have been used as extensively as CHOCKFAST ORANGE. Due to its extensive use, popularity, and availability, CHOCKFAST ORANGE was selected as the sole epoxy chock material for this study.

CHOCKFAST ORANGE, as received from the manufacturer, consists of a can of epoxy resin material and a plastic container of hardener (Figure 1). These two components,

8
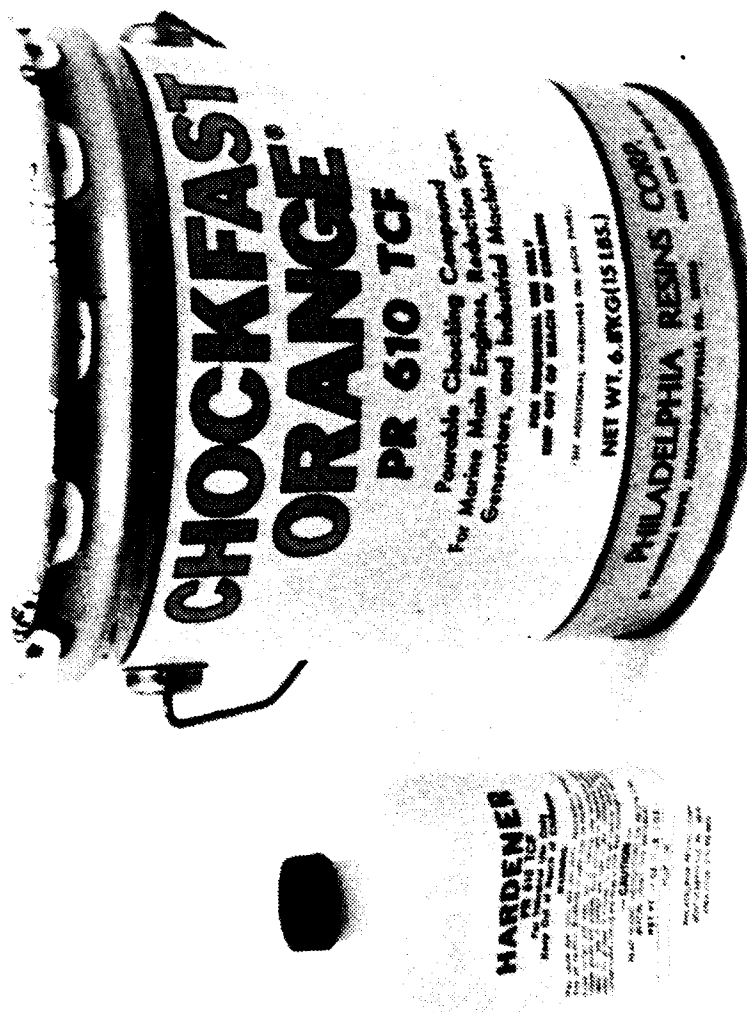
Figure 1.   CHOCKFAST ORANGE and Hardener

when mixed under the proper conditions produce a pastey orange material that is ready for immediate application. The method of application is known as Pour-In-Place-Chocks (PIPC) and is accomplished by first constructing a dammed area between a machinery/equipment mount and a bedplate. With the machinery aligned and the hold down bolts installed hand tight, the pastey orange material can be easily poured into the dammed area. The epoxy material cures and hardens in place resulting in a properly aligned apparatus with a strong support foundation.

Min. 12.7mm
(½") Overfill

Bedplate

Foam Rubber
Damming

Sealing Compound

ELEVATION SECTION

Foam Damming

Holding Down
Bolt. Greased

Front Dam
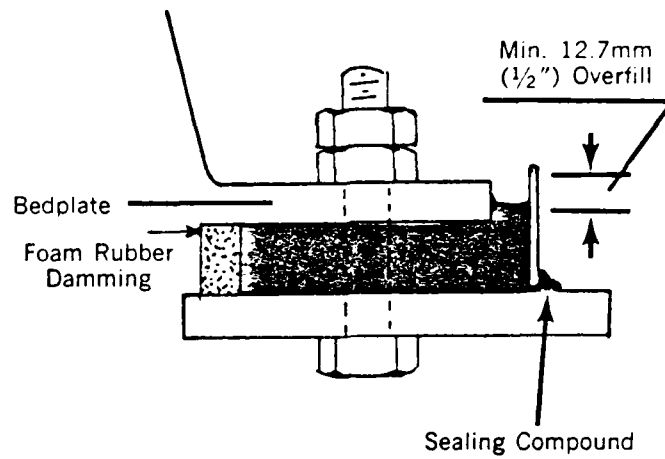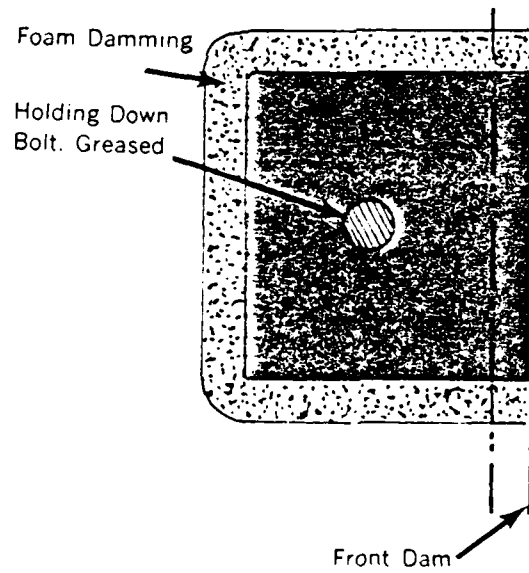
PLAN VIEW

Figure 2.   Pour-In-Place-Chock (PIPC)

11

II. HISTORY OF CHOCKING

In the past the standard chocking practice incorporated the use of steel shims for mounting heavy equipment and machinery. These shims had to be hand fitted and machined by skilled craftsmen to achieve the necessary tolerances for proper alignment. The fitting of the steel shims was accomplished primarily by a trial and error method and normally consumed many man hours of labor to satisfy the fine tolerances for alignment. In addition, the installed equipment and foundation mating surfaces had to undergo machining to ensure that the foundation to shim to equipment contact was intimately precise. After completion of the installation, the apparatus would occasionally fall out of alignment due to the processes of slipping, wearing, fretting, or long term creep. This would constitute the necessity of reinitializing the entire shimming procedure over again. The chocking process by way of shimming is not only extremely time consuming but also requires the need of skilled craftsmen. Both of these factors contribute to a very high cost requirement for this particular chocking method [Ref. 1].

Pour-In-Place-Chocks (PIPC) have been used in machinery and equipment installations on board ships for over

12

thirty-five years. The process provides for correct alignment and yields a sufficiently strong bearing surface area. The strength of the epoxy material to support the compressive loads of heavy equipment has proven to be very successful. In addition this chocking procedure does not have the problems of slippage, wearing, fretting, and long term creep as observed in the steel shim chocking method. Trained laborers instead of skilled craftsmen are used in the implementation of PIPC and the time expenditure is considerably less than the alternate older method. These advantages correspond to a much less expensive means of mounting shipboard machinery and equipment.

Some applications of PIPC presently on commercial and Naval ships include: [Ref. 2]

   a.   rudders

   b.   struts

   c.   reduction gears

   d.   main propulsion engines (diesel engines, steam and gas turbines

   e.   generators

   f.   pumps

   g.   winches

   h.   air compressors

   i.   weapons storage

   j.   elevator/bridge crane rails

   k.   sonar domes

l.   bearings (thrust, stern tube, spring, etc.)

m.   radar dome foundations

n.   antenna systems

The diversity of epoxy resin chock applications promotes
a strong economical alternative to the traditional steel
shim method [Ref. 3].

III.   THE NATURE OF EPOXY RESIN AND HARDENER

The word epoxy draws reference to a chemical group that
is composed of an oxygen atom bonded with two carbon atoms
that are already united by some other means. The most basic
example of an epoxy is a three-membered ring which has been
designated as an α-epoxy [Ref. 4]. Ethylene oxide is a
member of the α-epoxy family and is shown below:

$$O$$
$$CH_2{-}CH_2$$

Ethylene oxide
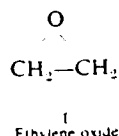
The term epoxy resin builds upon the word epoxy and
defines a molecule that contains more than one α-epoxy
group. These groups have the ability to be converted from
a liquid thermoplastic phase to a solid thermoset matrix
[Ref. 5].

Epoxy resin technology originated from research programs
conducted in both the United States and Europe prior to
World War II. The first resins occurred from the reaction
products of epichlorohydrin and bispherol A. These were
commercially produced in 1947 and within ten years resulted
in a production volume of 30 million pounds only to be
tripled in the six succeeding years. This thermosetting

15

class of plastics displays great versatility in use, low shrinkage, high chemical resistance, high electrical insulation, low viscosity, easy curing, and strong mechanical properties. The strength of properly produced epoxy resins normally exceeds that of most other casting resins. This can be partially attributed to the low shrinkage which prevents against high internal stress build-up [Ref. 6].

The most widely used liquid epoxy resin is known as diglycidyl ether of bisphenol A (DGEBA) which is the general constituent of CHOCKFAST ORANGE. Due to the confidentiality that Philadelphia Resins Corporation holds for it's product the specific manufacturing process of CHOCKFAST ORANGE was not obtainable. In general the synthesis of DGEBA occurs by reacting epichlorohydrin with bisphenol A in the presence of sodium hydroxide.

The raw material epichlorohydrin is synthesized from propylene and chlorine with dichlorohydrin as an intermediate, while bisphenol A is obtained from a reaction between phenol and acetone as shown [Ref. 7].
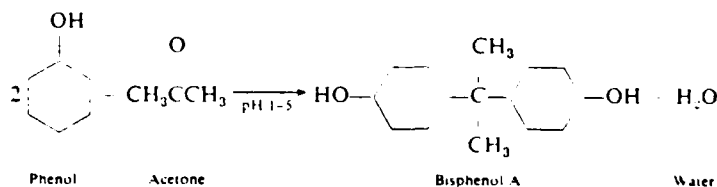
Due to the high availability of raw materials and the simplicity of production, bisphenol A is the primary dihydric phenol used in epoxy resin synthesis.

The reaction which produces the resin DGEBA is shown below [Ref. 8].

Bisphenol A   Epichlorohydrin

Chlorohydrin intermediate

Chlorohydrin intermediate - NaOH→DGEBA - salt and water
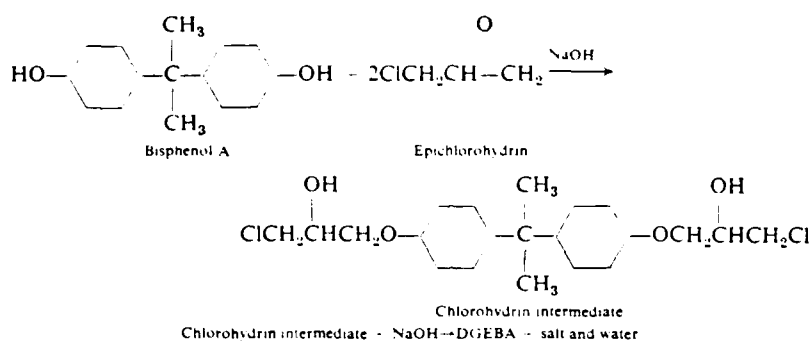
The sodium hydroxide caustic (NaOH) acts as a catalyst in the reaction to produce the chlorohydrin intermediate, then acts as the dehydrohalogenating agent, and finally neutralizes the formed hydrochloric acid. The resulting products of reaction are DGEBA plus salt and water. An atom model of the most widely used liquid epoxy resin DGEBA is shown in Figure 3 [Ref. 9].

One of the most important properties of an epoxy resin, such as DGEBA, is its ability to complete a transform from a liquidous thermoplastic state to a tough, hard thermoset solid. This conversion process is achieved by means of a chemically active compound referred to as either a hardener, a catalyst, or an activator. These three items are used

17
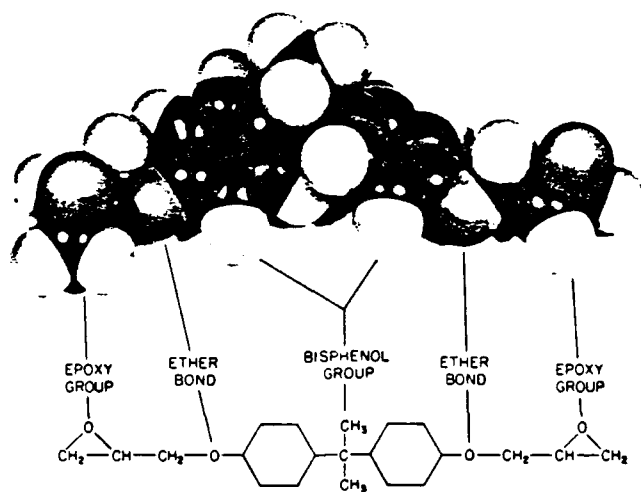
Figure 3.   Atomic Model of Liquid Resin DGEBA

synonimously in describing the curing agent for a particular resin.   Some curing agents react by pure catalytic action while others cause curing by becoming chemically fastened into the resin chain.   The type of curing agent used in the reactive process may either cause the transformation to occur at room temperature with heat produced exothermically or may require heat to be applied externally to promote the reaction [Ref. 10].

The most common curing agents found in epoxy-resin technology are Lewis bases, inorganic bases, primary and secondary amines and amides [Ref. 11].   Philadelphia Resins uses an amine as a hardener for CHOCKFAST ORANGE.   Again, due to the confidentiality the manufacturer holds for its product, no specific disclosure on the type of amine hardener used for CHOCKFAST ORANGE was obtainable.

18

IV. APPARATUS

A. SELECTION OF EQUIPMENT

After the choice of CHOCKFAST ORANGE as the epoxy
compound for use in this study it was necessary to acquire
its strength characteristics in the hardened, as cured
condition before proceeding on with equipment and
accompanying material selection. A table summary of
CHOCKFAST ORANGE PIPC major properties obtained from tests
conducted by the American Society of Testing Materials
(ASTM) and Lloyds of London is contained in Figure 4
[Ref. 12].

NAVSEA had specified a variety of chock sizes which were
of experimental interest in their pursuing study to obtain
information on PIPC. The size of the chock to be chosen had
a strong influence on the compressive test machine
selection. There were three available test machines for
potential use in this study. The first of these three was
the MTS, 100,000 pound fatigue machine which with the proper
jig could be converted into a suitable compressive loading
device. The second was the Tinius Olsen, 200,000 pound
tension/compression machine which with the exception of a
few minor modifications was immediately suitable for
compressive operation. The third machine was the Riehle,

300,000 pound tension device which required a significant jig modification to transform it into a useful compressive loading apparatus for epoxy resin chocks.

In consideration of the compressive load strength of 19,000 psi for CHOCKFAST ORANGE in Figure 4, and viewing the variety of NAVSEA recommended chock sizes along with the availability condition of the three compressive test machines, it was decided to use the Tinius Olsen 200,000 pound device with a chock size of 2" x 2"x 1 1/4". This combination put the compressive load the chock could withstand within comfortable limits of the test machine.

B. MOLD CONSTRUCTION

The next phase of apparatus development encompassed the construction of a mold to produce the 2" x 2"x 1 1/4" chock specimens. The CHOCKFAST ORANGE was obtained from the West Coast Philadelphia Resins Corporation distributor, Mr. George Kollock of Sausalito, California. A total of nine 15 pound cans of resin with accompanying hardener were purchased from the same lot (#060301). The volume capacity of a single can was 220 cubic inches. Realizing that a single can would comfortably produce 24 of the 2" x 2" x 1 1/4" specimens it was decided to create the samples enblock in lieu of 34 individual molds. Two enblock molds were fabricated using a 35 13/16" x 2" x 1 1/4" aluminum bar (Figure 5). This bar was first mounted in a plexiglass

20

ASTM test	Property	Chockfast Orange
	PHYSICAL	
D792	Specific gravity	1.59
D635	Flammability	passed test
	MECHANICAL	
	Hardness	
D2583	BARCOL	35-40
D2240	Shore Type D	
D695	Comprehensive strength (psi at 70°F)	19,000
D695	Modulus of elasticity (psi)	550,000
Lloyds	Creep (load & temperature limits)	500lb/in , 80°C
--	Impact strength (Izod ft/lb/in at 70°F)	.396
	CHEMICAL	
Lloyds	Fresh water resistance	
	% absorption after 24 hours	.032-.035
	% absorption after 72 hours	.055-.056
Lloyds	Oil resistance	
	% absorption after 24 hours	.015-.022
	% absorption after 72 hours	.021-.032
--	pot life (minutes)	25-60
D2566	Linear shrinkage (in/in)	.0002
	THERMAL	
--	Coefficient of Linear Thermal Expansion	
	in temperature range -75°C to 0°C	20.0 X 10 per C°
	in temperature range 0°C to 60°C	30.8 X 10 per C°
D648	Heat distortion temperature	93°C
BS2782-102D	Vicat softening point	299°C
	ELECTRICAL	
D149	Dielectric strength (V/mil)	440
D495	Arc resistance (seconds)	185

Figure 4. Properties of CHOCKFAST ORANGE

Figure 5. Aluminum Bar Used in Mold Construction

encasement that was 37 1/2" long, 5 3/16" wide, and 4" deep. All edges and corners of the plexiglass were sealed with melted wax. Silicon RTV obtained from Silastic Corporation of Sunnyvale, California was then mixed in accordance with manufacturer's instructions, placed in a vacuum chamber for approximately five minutes to extract entrained air bubbles, and then finally poured over the aluminum bar and wooden alignment dowels inside the plexiglass encasement. A picture of the vacuum chamber is shown in Figure 6. After 48 hours of allowing the silicon RTV to cure and harden the 1/2 mold portion was removed and turned around so that the second half of the mold could be poured.

Prior to this pour the wooden alignment dowels were also taken out and a light film of mold release was sprayed on the mating surface of the first mold portion. Another container of Silicon RTV was mixed, placed in the vacuum chamber for five minutes, and then poured into the plexiglass encasement which housed the first half of the mold along with the accompanying aluminum bar. Again 48 hours was allowed to elapse for proper curing and hardening. This entire procedure was repeated to construct a second complete mold. A mold with the accompanying aluminum bar is seen in Figure 7. Each was designed with one end open which would permit pouring of the mixed epoxy liquid material at a steeply inclined angle. It was believed that this method
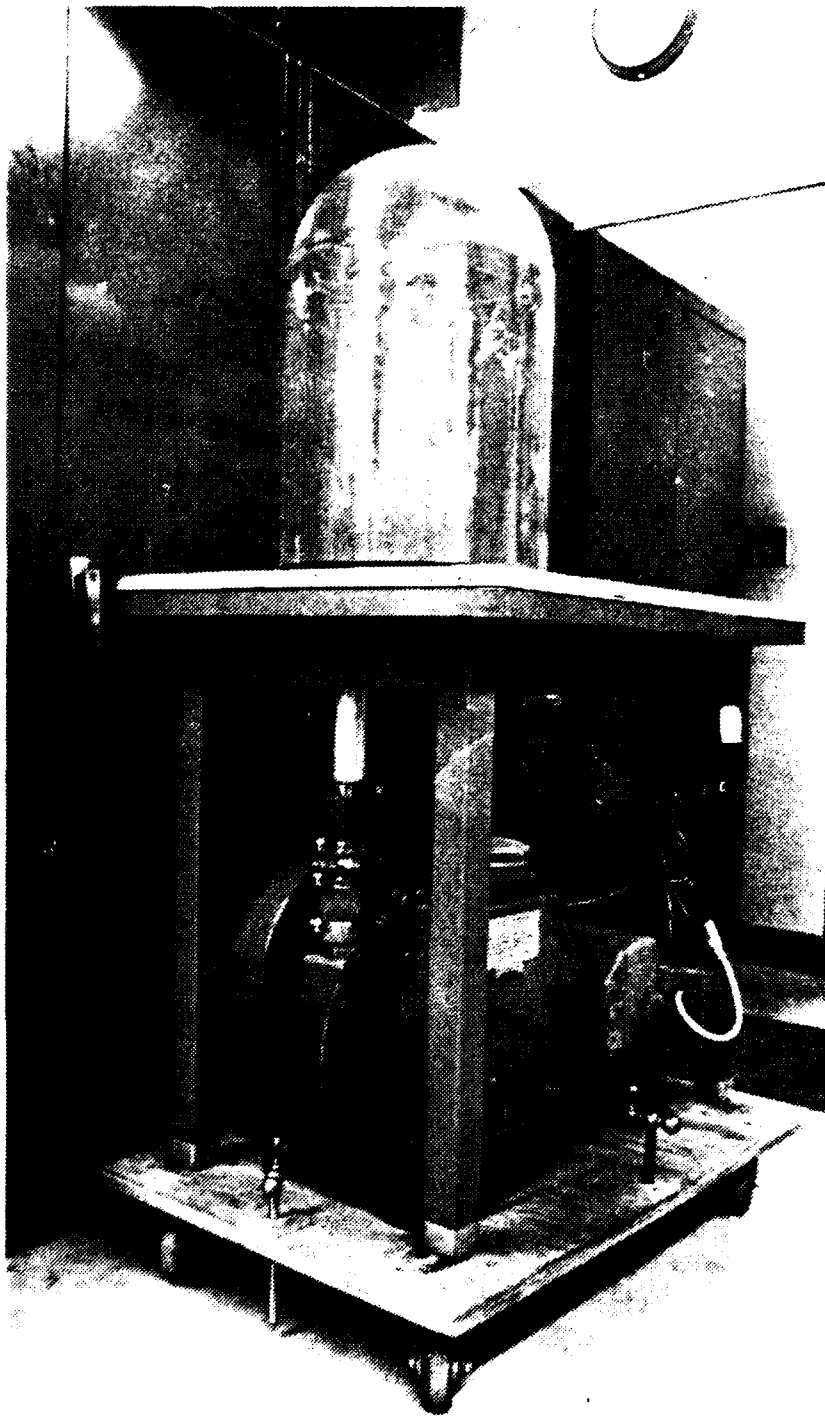
Figure 6.   Vacuum Chamber

24
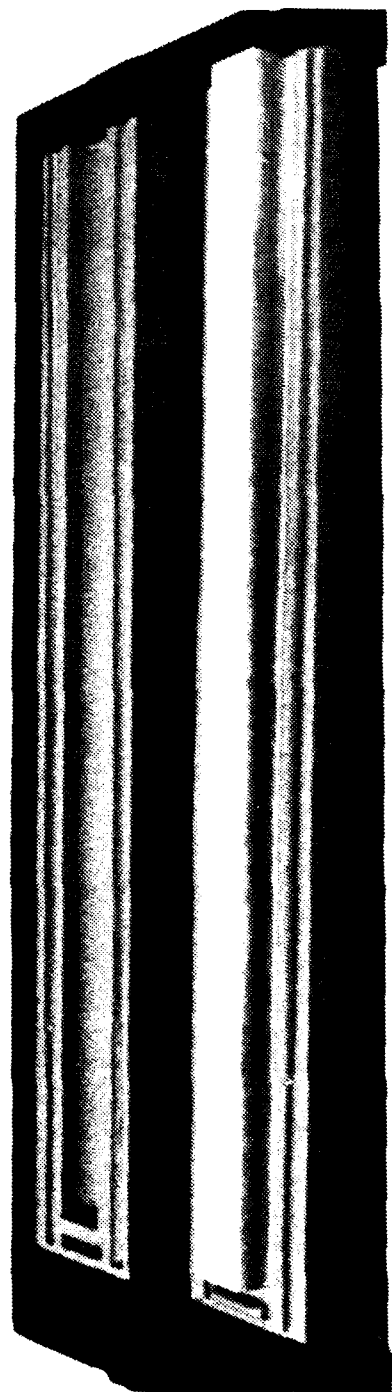
Figure 7. Mold with Accompanying Aluminum Bar

25

would minimize air entrapment during the pouring of the
epoxy liquid material. The design and construction of two
molds in lieu of one facilitated the ensuing handling and
the cutting processes. The final molds displayed dimensions
of 37" in length, 5 1/4" in width, and 2 3/4" in depth.

C.   EXTERNAL MOLD REINFORCEMENT

Although the silicon RTV provided a suitably refined
interior surface for the epoxy pouring it was found that
external reinforcement was necessary to prevent the molds
from warping or separating during pouring of the CHOCKFAST
ORANGE. The flexibility of this mold material is shown in
Figure 8. Initially a 3/8" thickness plywood container
consisting of two halves was constructed to fit snuggly
around one of the molds (Figure 9). The halves were held
together by six strategically located clamps. The first
pour of epoxy was then attempted and yielded a warped
35 13/16" long orange specimen of variable thickness and
width. This mold reinforcement method was deemed
unsuitable. A second attempt incorporated the use of two
37" x 7" x 3/4" plywood boards secured by eight 5" x 3/8"
bolt to nut fasteners. The mold was sandwiched between
these two boards and the bolts were hand tightened to a
torque which would not allow for any appreciable deformation
of the Silicon RTV mold structure. Two of these two board
external mold reinforcement devices were fabricated, one for

26
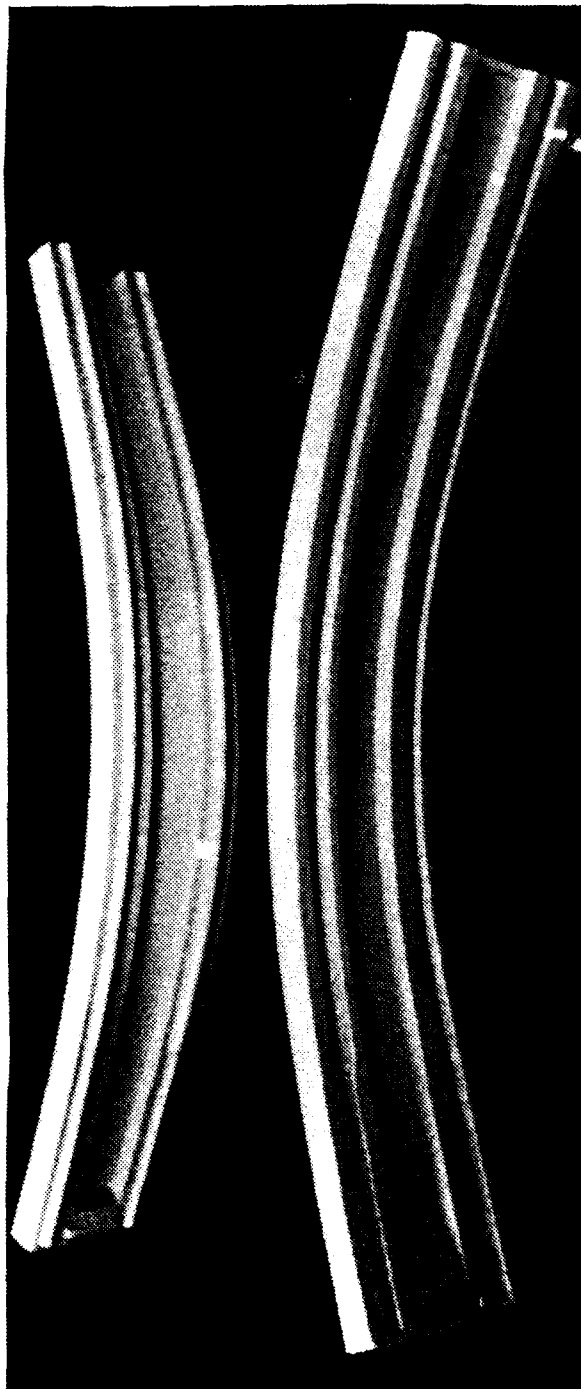
Figure 8. Flexibility of RTV Mold

27
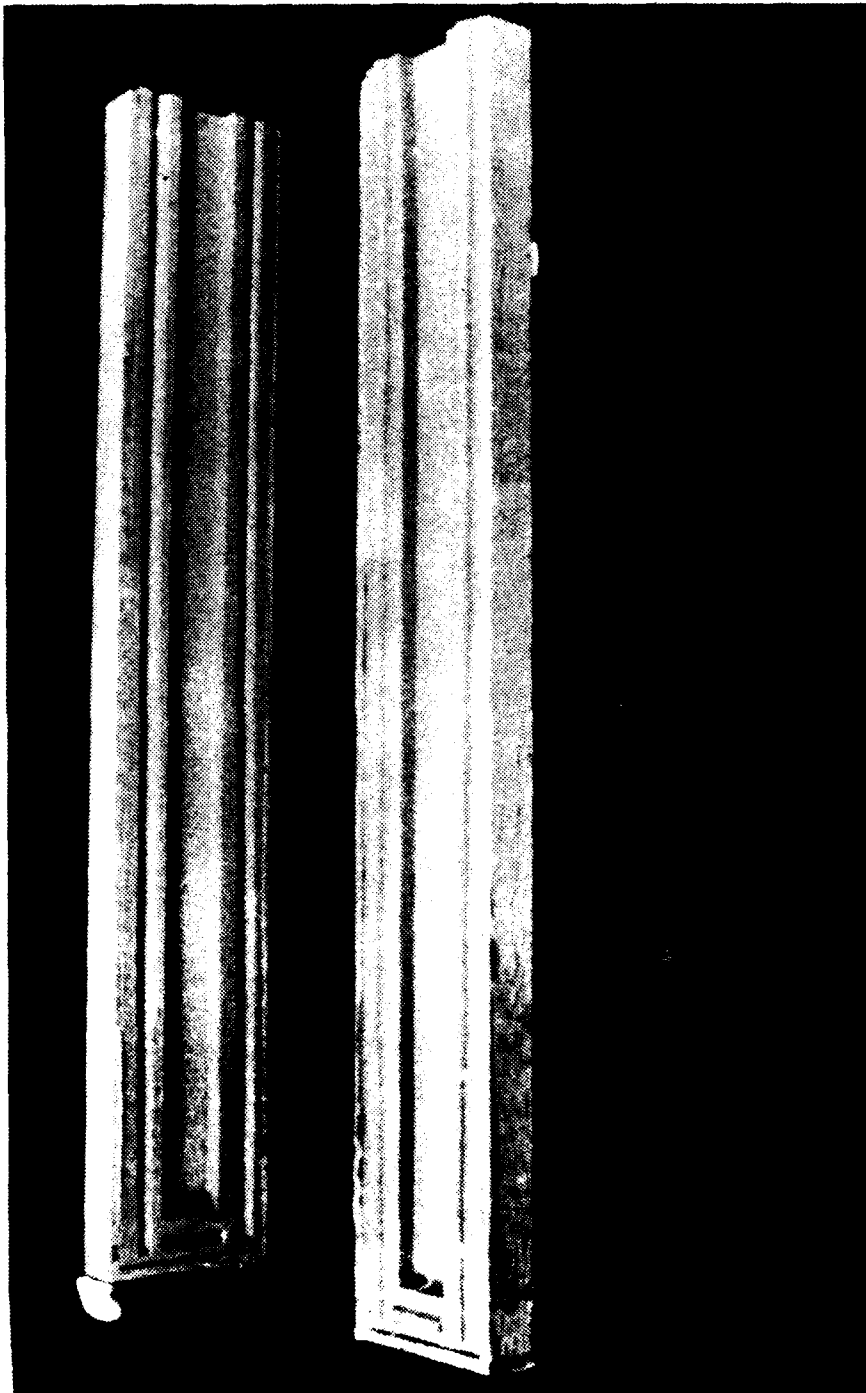
Figure 9. External Mold Reinforcement, Plywood Container

28

each mold (Figure 10). These proved satisfactory in minimizing the chock specimen warping as well as thickness variability and became a standard part of the epoxy pouring apparatus.
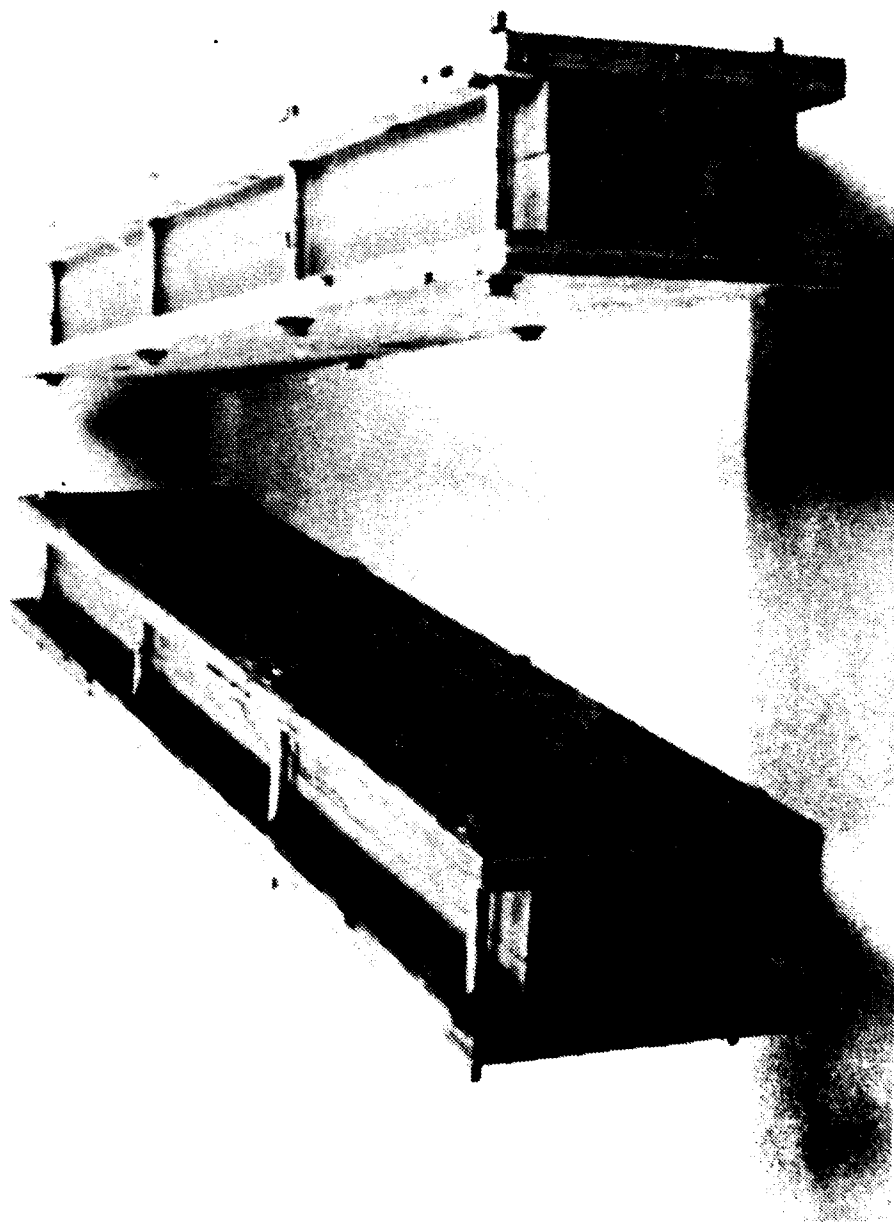
Figure 10. External Mold Reinforcement, Plywood Boards

V. MIXING AND POURING PROCEDURE OF CHOCKFAST ORANGE EPOXY RESIN AND HARDENER

The mixing and pouring procedure for CHOCKFAST ORANGE was conducted with only minor exception in accordance with Philadelphia Resins Corporation's Mechanical Bulletin No. 654.

The resin and hardener, in all cases, were maintained at a temperature of approximately 21.5°C for at least twelve hours prior to mixing and pouring. One 15 lb. can of CHOCKFAST ORANGE was then mixed with the appropriate amount of hardener using a heavy duty hand electric drill connected to a variac. This connection permitted the drill to operate at the manufacturer's recommended speed of 200 RPM. The specially designed mixing blade provided by Philadelphia Resin's west coast distributor was affixed to the drill and the mixing process was conducted for a duration of three minutes and fifteen seconds. The amount of hardener used was consistent in all mixtures. Each bottle holds seventeen fluid ounces of hardener and is marked with a reduced pour line. Since the silicon RTV mold material is a much better insulator than a steel or aluminum foundation as would be in normal application of CHOCKFAST ORANGE, a full reduction of hardener was used. The metallic surfaces have a much higher conductance than the silicon rubber and can carry off the

31

exothermic heat of reaction of the curing epoxy more readily. The curing environment within the mold therefore required less hardener and from the manufacturer's recommendations only the amount of hardener down to the reduced pour line was used in the mixing process [Ref. 6].

During the process the drill blade was made to traverse all internal portions, sides and bottom, of the CHOCKFAST ORANGE can ensuring the complete mixing of all resin and hardener. Approximately ten minutes of dormancy were allowed so as to permit any entrained air bubbles to naturally rise to the surface and exit the liquid epoxy. This procedure was recommended by the manufacturer's representative and is common when the resin and hardener are mixed in a shipyard environment. The vacuum chamber was intentionally not used for this purpose so that the final epoxy product would simulate as close as possible the quality of chocks that would be found on most shipboard applications.

The silicon RTV molds were first prepared for epoxy pouring by a careful cleaning of the mating surfaces and epoxy cavities of each mold half. The cleaning was accomplished by high pressure air which effectively removed any loose particles and dust accumulation. A light film of vasoline was next applied to the half mold contact surfaces to provide a good seal when mated with its corresponding

32

counterpart thusly preventing any undesirable leakage. The epoxy cavity surface was treated with Philadelphia Resin's spray mold release even though silicon RTV naturally does not adhere to cured epoxy. The mold halves were then mated and each mold was then placed into its respective external reinforcement device as described earlier.

The pouring occurred with the molds inclined at a steep angle (75 - 85 degrees from the horizontal) with the open end facing up. The mixed can of liquid epoxy was then elevated to approximately 2" above the first mold opening from where pouring commenced. The liquid CHOCKFAST ORANGE was made to slowly flow down the 35 13/16" x 2" inclined side so as to minimize air entrapment. Once filled, the mold was placed in a directly upright position and then the same pouring procedure was repeated for the second mold. This pouring technique as opposed to a direct upright pour proved more efficient in keeping a homogenous epoxy medium inside the molds. This point of concern is emphasized because of the earlier decision to design the epoxy chocks in an enblock configuration with subsequent cutting to acquire the finally selected 2" x 2" x 1 1/4" chock size. The enblock epoxy pour still showed evidence of small air accumulation as could be observed from the rising bubbles appearing at the open end of each mold. The effect of the entrapped air bubbles on the compressive strength of the

33

epoxy chocks proved to be insignificant. The environmental temperature during curing was maintained at approximately 21.5°C with hardening of the epoxy liquid observed at three to four hours after the pour. The epoxy enblock chocks, however, were not removed from the molds until 48 hours after the pour took place. This ensured total curing of the epoxy compound [Ref. 14].

VI. CUTTING OF ENBLOCK CHOCKS

The final phase in the production of the 2" x 2" x 1 1/4"
chocks was cutting the 35 13/16" x 2" x 1 1/4" enblock
CHOCKFAST ORANGE epoxy bars into 2" segments. The initial
attempt included the utilization of a Grob band saw.
Although this resulted in successfully cutting through the
epoxy material, two undesirable drawbacks were observed.
The first was economical in that the band saw blade had
become dull to the point where replacement was necessary.
Since this was just the first of many epoxy enblock bars to
be cut it was decided that another more cost effective means
of cutting had to be found. Secondly, and most important
was that the band saw cutting process caused significant
heating of the epoxy matrix material. This could not be
acceptable as there was no way to determine what effect, if
any, the localized heating was having on the material
properties of the epoxy chocks.

The next cutting attempt incorporated the use of a
radial saw with a carburundum blade. Again, a high tempera-
ture was generated from this cutting device eliminating this
as a possible cutting method. Additionally, a blade wear
problem was also evident from this process.

Information acquired from the CHOCKFAST ORANGE
manufacturer's representative related that the epoxy

material was impregnated with very fine silica particles
which would cause significant frictional heating and blade
weardown. A water cooled radial saw with a diamond tip
blade was recommended as a cutting assembly. This was
acquired from the NPS Aeronautics Department in Halligan
Hall and was moved to the Mechanical Engineering Building
500 where it was set up (Figure 11). This building was more
isolated and better suited for the cutting process which
generated fair amounts of epoxy dust particles. This
cutting assembly was successful in eliminating the problems
of frictional heating and blade weardown. At all times
protective masks were used as a safety device during the
cutting procedure.
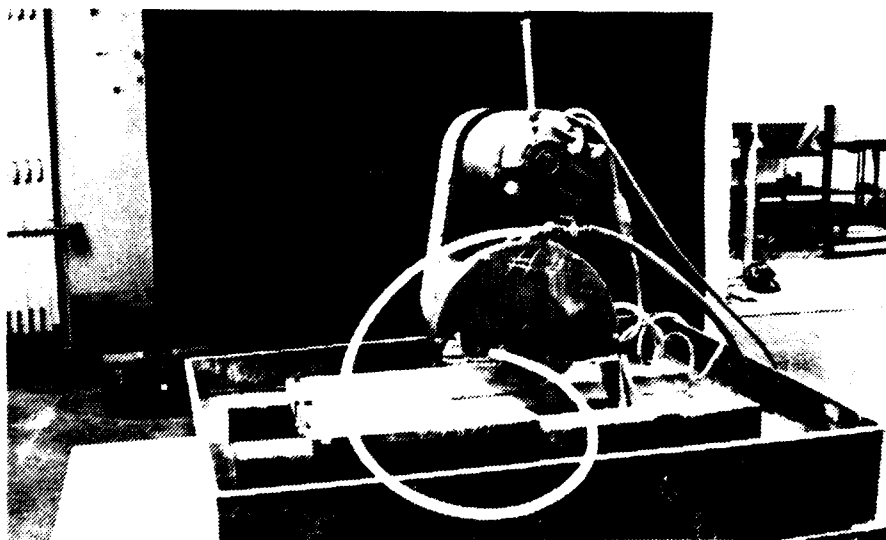
Figure 11. Water Cooled Radial Saw with Diamond
Tipped Blade

36

VII. ELEVATED TEMPERATURE EXPOSURE OF CHOCKFAST ORANGE EPOXY RESIN CHOCKS

Initially two furnaces were selected as the elevated temperature exposure environments for the 2" x 2" x 1 1/4" epoxy resin chocks. A Blue M Electric Company furnace and a Thermolyne Corporation furnace were each set at a temperature of $120^{\circ}C$ and monitored by a suitably ranged celcius thermometer and thermocouple. The $120^{\circ}C$ temperature represented approximately the middle of the elevated temperature field for the heating of the chocks. After each furnace achieved a steady state condition, close observation of temperature fluctuation and drift was conducted for a period of five days. The Blue M displayed a $\pm2^{\circ}C$ variation with no drift while the Thermolyne fluctuated at $\pm11^{\circ}C$ with a drift of approximately $5^{\circ}C$. Due to the large inconsistencies in the Thermolyne temperature control the furnace was deemed unacceptable for use in this experiment. The Blue M Electric Company furnace model no. CW-7712, serial no. EP-1755, 440 volt/3 phase/60 cycle, with a temperature range up to $649^{\circ}C$ was selected due to its much greater ability to hold a preset temperature with no drift and minimal fluctuation (Figure 12).

The chocks obtained from the epoxy pouring process were then separated into six groups of twelve specimens each. In

37
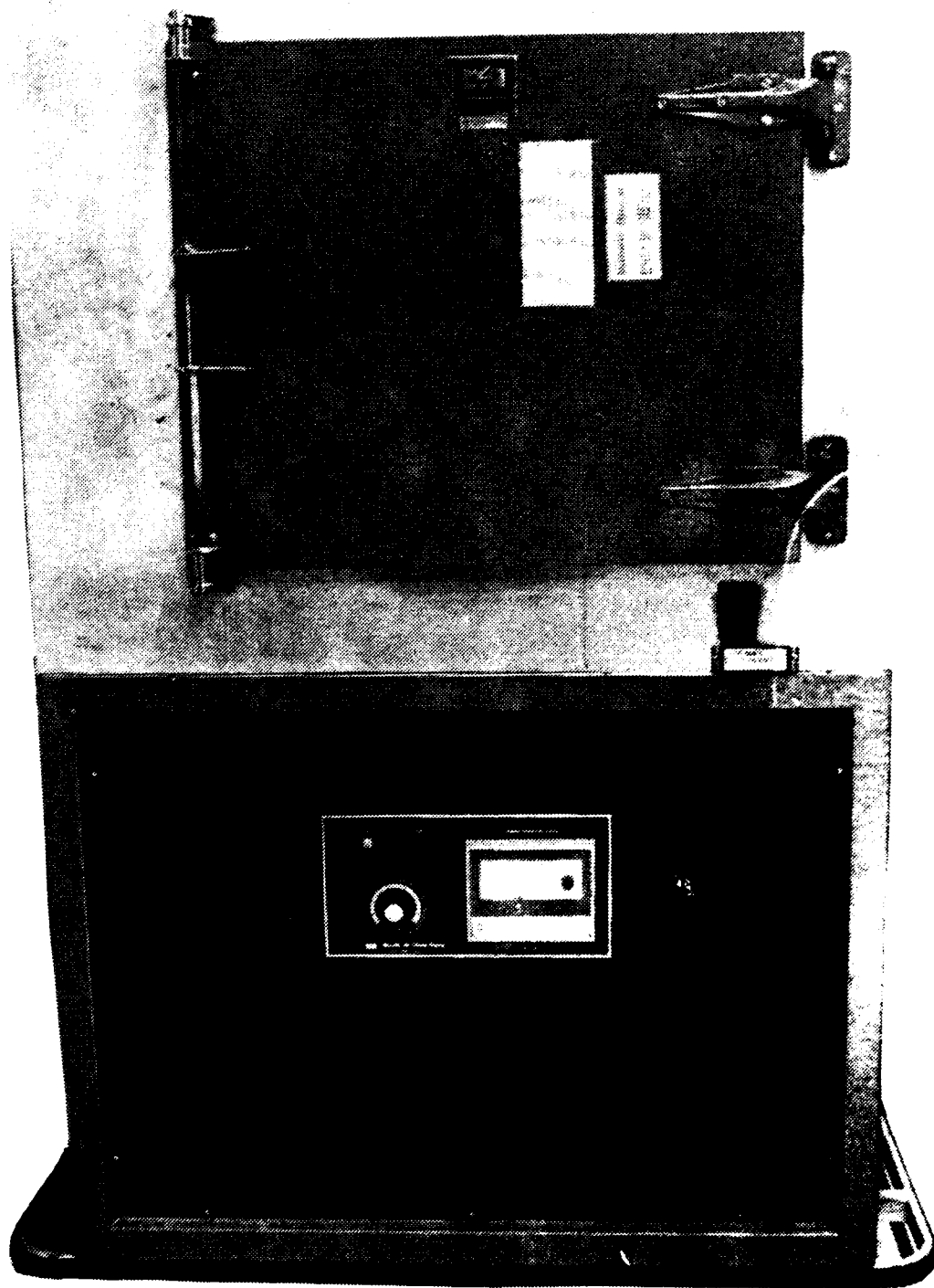
Figure 12.   Blue M Electric Company Furnace

order to maintain accountability all chocks from each group were marked prior to being placed into the elevated temperature environment with a smearproof felt tip applicator containing black ink (Figure 13). The marking system, reading from left to right, incorporates the temperature in centigrade to which the chocks would be subjected, the number 1, 2, or 3 corresponding to the duration times of 24, 72, or 120 hours respectively, and then the specimen number 1, 2, 3, or 4 for that particular duration time.
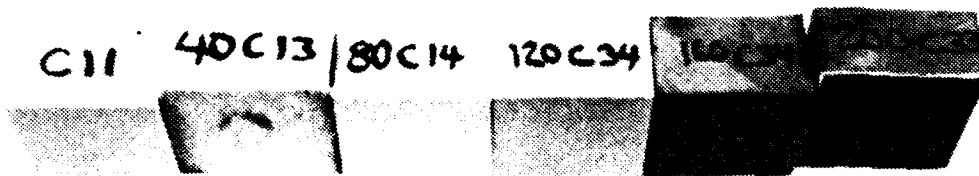
Figure 13. Marked Epoxy Chocks

According to Philadelphia Resins Corporation representative Robert Sciblo, very little data is available on the elevated temperature exposure of CHOCKFAST ORANGE above 80°C. Limited information provided by the manufacturer did

39

indicate that CHOCKFAST ORANGE, at an approximate tempera-
ture of 250°C, would begin releasing carbon monoxide gas in
conjunction with a black smoke. In order to positively
avoid the hazard of carbon monoxide, the temperature of
200°C was chosen as the upper limit for this study.
Therefore, the elevated furnace temperatures selected for
this experiment were 40°C, 80°C, 100°C, 120°C, 160°C, and
200°C with a control established at a room temperature of
21.5°C. The twelve specimens comprising each group were
chosen from the same CHOCKFAST ORANGE pour so as to avoid
any possible inconsistencies arising between the chock group
members. The Blue M furnace was then brought up to one of
the selected temperatures and allowed to reach a steady
state condition. Once the proper environment was achieved a
marked group of chocks was placed into the furnace. At each
duration of 24, 72, and 120 hours, four specimens were
removed. These time periods for chock removal from the
furnace were arbitrarily chosen since no information on how
the time-temperature variables effected the material
properties of CHOCKFAST ORANGE was available. An in furnace
view with chocks and thermometer is seen in Figure 14.

The 100°C elevated temperature was chosen in retrospect
after observing a trend established by the other groups.
This trend displayed a sensitive transition area between the
80°C to 120°C temperature interval. The removal time

40
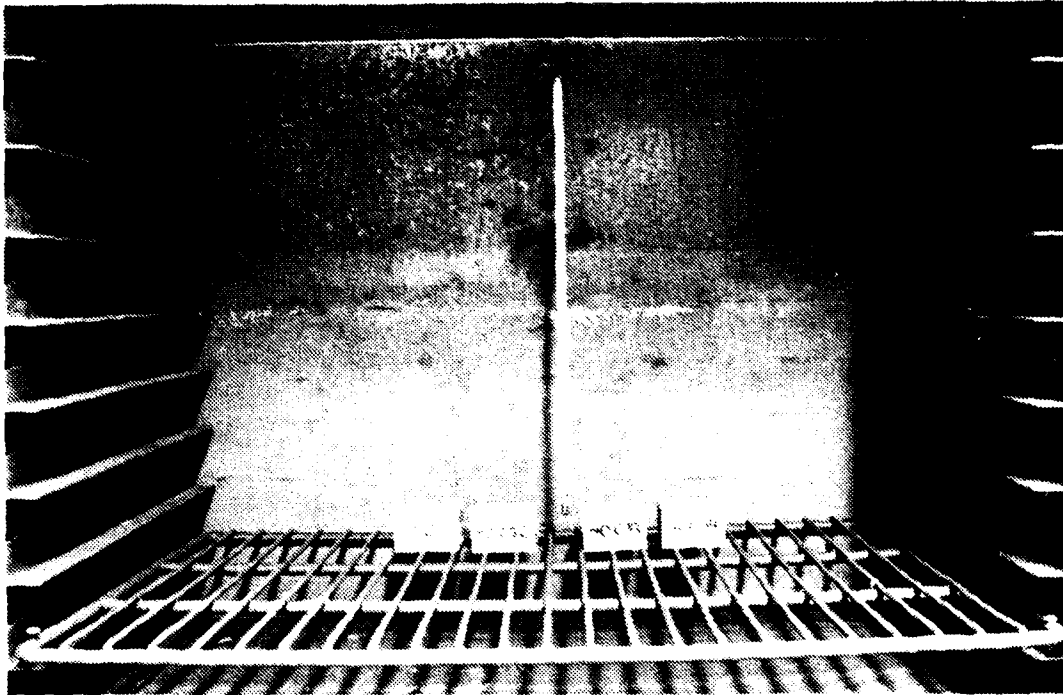
Figure 14.   In Furnace Chock Location
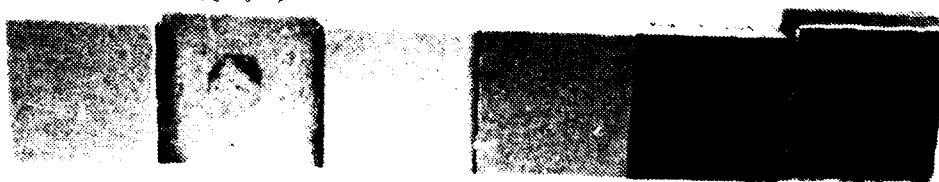
Figure 15.   Epoxy Chock Elevated Temperature Discoloration

41

periods selected for this group were 6, 18, 36, and 48 hours.

The chocks experienced a significant amount of discoloration from the higher temperatures as can be observed in Figure 15. The discoloration ranged from its natural appearance of bright orange up through $80^{\circ}C$, orange-brown at $120^{\circ}C$, brown at $160^{\circ}C$, and finally black at $200^{\circ}C$.

After the epoxy resin chocks were removed from the furnace, the specimens were allowed to cool to ambient conditions for a minimum duration of 48 hours before undergoing a compressive load test. This is in compliance with the American Society of Testing Materials (ASTM) designation D 695, Standard Method of Test for Compressive Properties of Rigid Plastics. This ASTM standard directs that all specimens to be compressively loaded must be conditioned at $23 \pm 2^{\circ}C$ and 50 ± 5 percent relative humidity for not less than 40 hours prior to testing. Temperature and humidity measurements taken during the period were in agreement with this criteria.

VIII. <u>COMPRESSION TESTING OF CHOCKFAST ORANGE</u>
<u>EPOXY RESIN CHOCKS</u>

The Tinius Olsen, 200,000 lb. capacity, Super "L" hydraulic universal testing machine, 240 volt/60 cycle/3 phase with serial no. 54144, was used for the compressive loading of the 2" x 2" x 1 1/4" epoxy chock specimens (Figure 16). This machine uses a hydraulic load value and from a fixed pre-adjusted position will maintain a constant load speed for each specimen. The machine did not provide a means for determining compressive deformation of the test material. In order to accomplish this task a Brown and Sharpe .001" graduation, 1" range dial indicator fastened to a brass block was positioned between the hydraulic powered base and the crosshead. Due to the clearance constraints of the apparatus, the fabrication of a 5" x 5" x 21/32" stainless steel plate and a 5" x 5" x 7/16" aluminum plate was necessary. The steel plate was situated just under the chock specimen and the aluminum plate provided a base for the dial indicator assembly. The entire setup is shown in Figure 17. All chocks were tested at constant loading rate which complied with ASTM designation D 695 Section 8.2. This specification indicates that the speed of constant cross head movement shall be 1.3 $\pm$ 0.3 mm per minute (.05 $\pm$ .01 in/min).

43
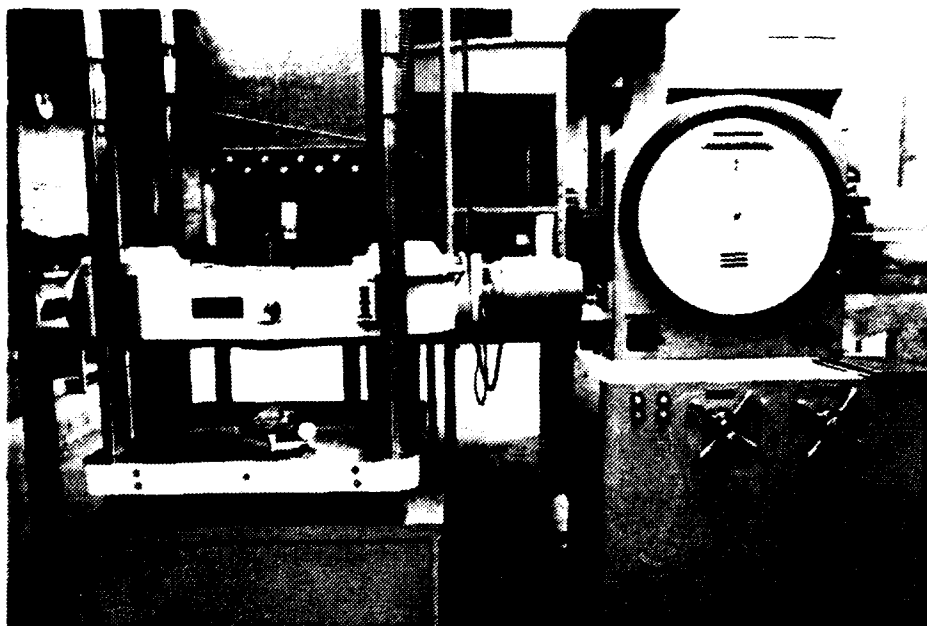
Figure 16. Tinius Olsen Compression Testing Machine
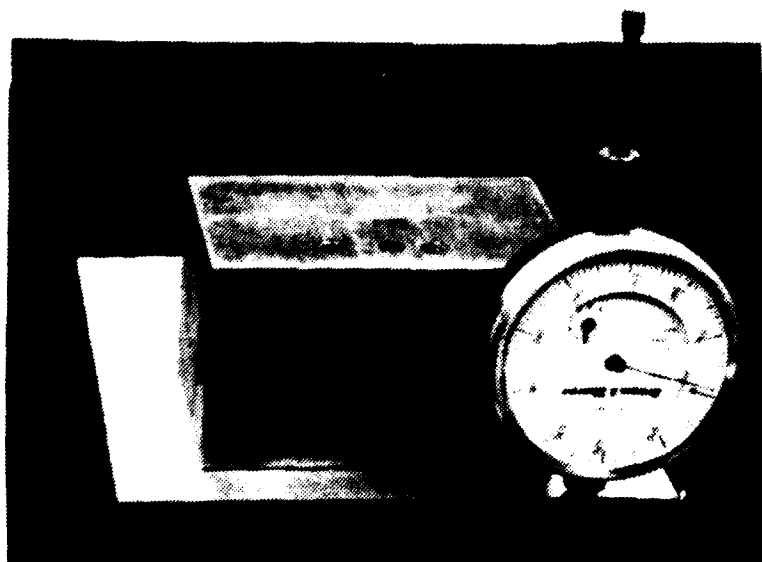
Figure 17. Dial Indicator Assembly

44

The compressive testing procedure entailed the need for two persons to collect the data. One person was responsible for reading the dial indicator and verbally notifying the other at regular intervals when a specified amount of compressive deformation of the epoxy chock had been reached. The second person would then record the compressive load on a raw data sheet. A typical raw data sheet is shown in Figure 18.

An investigation into a more sophisticated automatic data acquisition system was initially undertaken but the prospect was dismissed due to expensive cost estimates and long waiting time for delivery and apparatus construction. Although the two person procedure consumed a significant amount of man-hours it more than compensated for the large delay in start time expected from devising the automatic data acquisition system.

Each CHOCKFAST ORANGE pour provided for 34 usable epoxy chocks divided into two twelve specimen groups and ten individual specimens. Each group was subjected to a separate elevated temperature environment while the ten individual specimens remained at ambient conditions and acted as a control. At 24, 72, and 120 hour periods, four specimens from the particular group undergoing elevated temperature exposure would be removed. Although four specimens were removed in most cases only three would be

Tinius Olsen Compression Test Data Sheet

INCHES	#
.000	
.004	
.008	
.012	
.016	
.020	
.024	
.028	
.032	
.036	
.040	
.044	
.048	
.052	
.056	
.060	
.064	
.068	
.072	
.076	
.080	
.084	
.088	
.092	
.096	
.100	
.110	
.120	
.130	
.140	
.150	
.160	
.170	
.180	
.190	
.200	
.210	
.220	
.230	
.240	
.250	

Sample __C31__

Area __1.958__ × __1.971__ in^2

Thickness __1.246__ in

σ_c = _____ PSI

Recorder __MV__

Date _____

Figure 18. Typical Raw Data Sheet

46

subjected to a compressive load test with the remaining one chock acting as a back up. After the specimens returned to room temperature over 48 hours they along with three control chocks were tested under a compressive load. Since the control chock compressive strength was not expected to undergo any change the remaining seven chocks were sporadically tested over the succeeding interval as a check to confirm this information. The procedure for compressively loading the elevated temperature specimens was repeated for the two sets of four chocks remaining from the first group. The second elevated temperature group was then brought through the same testing routine.

A total of three pours were utilized in this elevated temperature exposure and compressive loading experiment, each providing a separate control for the two accompanying elevated temperature groups.

The compressive loading caused the appearance of star like markings on the sides of the chocks (Figure 19). This phenomena seemed to indicate a type of internal ongoing buckling of the epoxy material. The applied load apparatus produced a localized orientation of the macromolecular chains resulting in an abrupt and concentrated internal slip. This effect occurred only in the plastic portion of the compressive deformation process and was observed in all specimens.
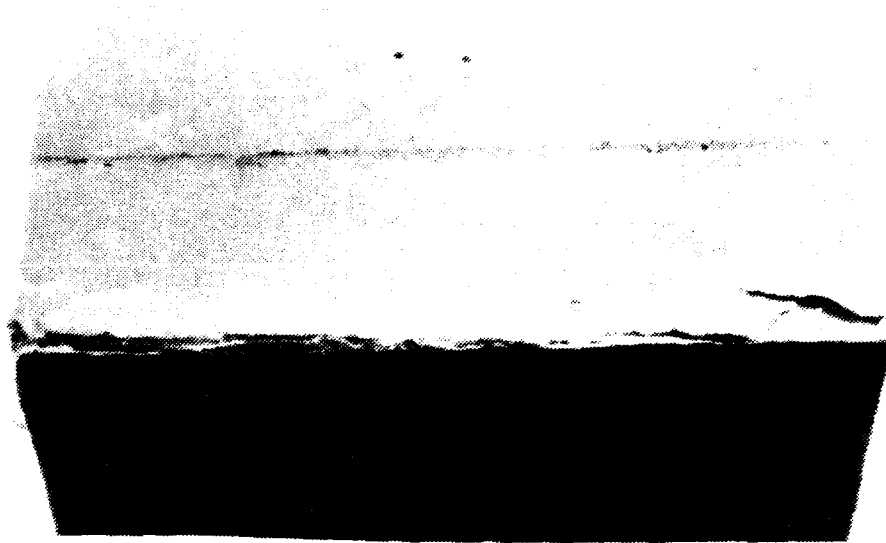
Figure 19. Epoxy Chock Star Like Markings from Compression Testing
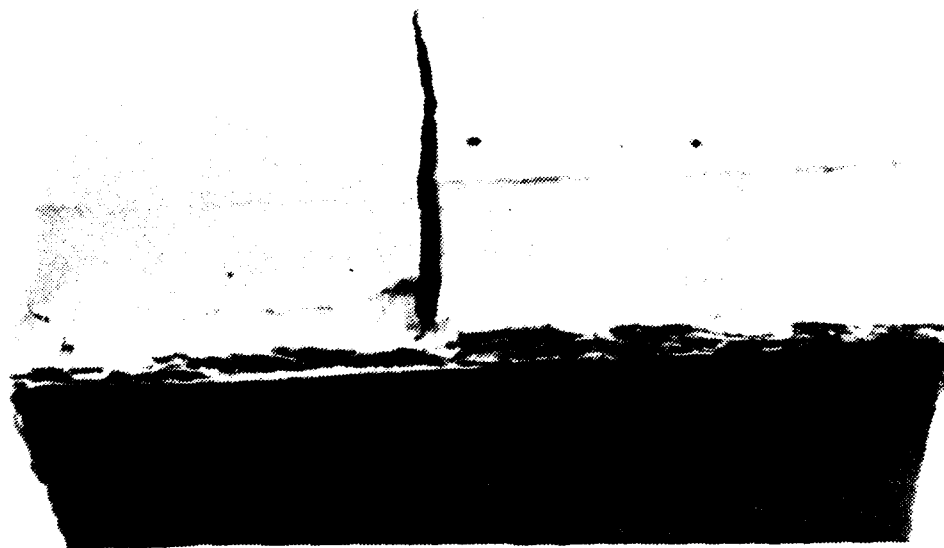
Figure 20. Typical Fracture of an Epoxy Resin Chock

Final failure of the epoxy chock specimens varied in nature. A large increase in compressive deformation combined with a significant decrease in load and no obvious material fracture was characteristic of the experimental control specimens. The chocks that were exposed to greater elevated temperatures would fail primarily by rapid fracture of the material as shown in Figure 20. These specimens underwent a considerably more extensive amount of compressive deformation.

IX.   EXPERIMENTAL RESULTS

Ultimate stress and strain calculations were performed on all of the epoxy chock specimens that were subjected to compressive loading.   In all cases, with the exception of the 24 hour exposure at 40°C, the average ultimate compressive strength of the elevated temperature specimens exceeded the average of the control specimens.   This is tabulated in Figures 21 through 26.   A plot of average ultimate strengths vs. temperature (21.5°C, 40°C, 80°C, 120°C, 160°C, and 200°C) at 24, 72, and 120 hours is contained in Figures 27, 28, and 29 respectively.   These indicate the significant progressive increase of ultimate strength particularly between the 80°C and 120°C temperatures with a leveling off occurring at the 120°C to 160°C temperature interval and a slight decline observed at the 160°C to 200°C temperature segment.

Point by point stress versus strain calculations for the control chocks and each maximum duration elevated temperature exposure set were carried out and averaged from the raw data sheets.   The subsequent plots are contained in Figures 30 through 35.   These plots were used to calculate the engineering yield strength and elastic modulus as tabulated in Figure 36.   Due to the gradual transition

CONTROL 1

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
C11	3.858	1.255	75,200	19,492	.0510	--	130
C12	3.822	1.269	75,200	19,676	.0473	--	
C13	3.890	1.239	76,800	19,742	.0484	--	
			Average	19,637	.0489	--	

80°C SPECIMENS (24 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
80C11	3.928	1.244	80,750	20,557	.0579	--	156
80C12	3.897	1.268	81,250	20,848	.0757	--	
80C13	3.858	1.247	80,250	20,801	.0674	--	
			Average	20,735	.0670	5.59	

80°C SPECIMENS (72 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
80C21	3.900	1.261	86,500	22,178	.1934	--	171
80C22	3.891	1.257	85,500	21,975	.1321	--	
80C23	3.869	1.262	84,500	21,838	.1268	--	
			Average	21,997	.1508	12.02	

80°C SPECIMENS (120 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
80C31	3.928	1.231	87,375	22,245	.1462	--	69
80C32	3.842	1.220	85,500	22,257	.1722	--	
80C33	3.800	1.222	85,000	22,370	.1800	--	
			Average	22,291	.1661	13.52	

Figure 21. Ultimate Strength Table for Control 1 and 80°C Specimens

200°C SPECIMENS (24 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev (psi)
200C11	3.868	1.246	97,000	25,080	.1911	--	
200C12	3.929	1.248	98,000	24,945	.2083	--	159
200C13	3.897	1.261	96,500	24,763	.1903	--	
			Average	24,929	.1966	26.95	

200°C SPECIMENS (72 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev (psi)
200C21	3.873	1.235	98,000	25,304	.2105	--	
200C22	3.848	1.235	95,750	24,884	.1943	--	356
200C23	3.903	1.251	96,000	24,596	.2078	--	
			Average	24,928	.2042	26.94	

200°C SPECIMENS (120 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev (psi)
200C31	3.901	1.250	96,125	24,634	.2080	--	
200C32	3.908	1.247	98,250	25,141	.1924	--	407
200C33	3.916	1.248	99,625	25,440	.1923	--	
			Average	25,072	.1976	27.68	

Figure 22. Ultimate Strength Table for 200°C Specimens

52

CONTROL 2

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
C21	3.847	1.285	74,847	19,461	.1230	--	
C22	3.858	1.260	75,750	19,633	.0571	--	192
C23	3.857	1.237	74,250	19,249	.0485	--	
Average				19,441	.0528	--	

120°C SPECIMENS (24 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
120C11	3.896	1.249	98,250	25,219	.1681	--	
120C12	3.894	1.254	101,000	25,938	.1834	--	466
120C13	3.930	1.253	98,500	25,064	.1676	--	
Average				25,407	.1730	30.69	

120°C SPECIMENS (72 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
120C21	3.870	1.252	97,375	25,161	.1678	--	
120C22	3.933	1.251	101,250	25,742	.1679	--	513
120C23	3.904	1.241	96,500	24,719	.1450	--	
Average				25,207	.1602	29.66	

120°C SPECIMENS (120 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
120C31	3.896	1.251	100,000	25,670	.1599	--	
120C32	3.901	1.259	96,000	24,610	.1509	--	535
120C33	3.888	1.247	98,250	25,269	.1444	--	
Average				25,183	.1517	29.54	

Figure 23. Ultimate Strength Table for Control 2 and 120°C Specimens

160°C SPECIMENS (24 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
160C11	3.890	1.292	98,625	25,352	.1858	--	
160C12	3.875	1.284	97,875	25,260	.1947	--	261
160C13	3.831	1.286	95,250	24,861	.2022	--	
		Average		25,158	.1942	29.41	

160°C SPECIMENS (72 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
160C21	3.849	1.267	96,875	25,167	.1973	--	
160C22	3.988	1.282	98,500	24,699	.2106	--	414
160C23	3.859	1.235	98,500	25,525	.2105	--	
		Average		25,130	.2061	29.26	

160°C SPECIMENS (120 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
160C31	3.769	1.248	95,125	25,241	.2003	--	
160C32	3.901	1.238	99,125	25,413	.1777	--	100
160C33	3.890	1.251	98,875	25,417	.1998	--	
		Average		25,357	.1926	30.43	

Figure 24. Ultimate Strength Table for 160°C Specimens

CONTROL 3

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
C31	3.865	1.258	77,375	20,019	.1510	--	347
C32	4.029	1.222	78,125	19,392	.1309	--	
C33	4.026	1.245	80,375	19,965	.1446	--	
			Average	19,792	.1422	--	

40°C SPECIMENS (24 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
40C11	3.845	1.266	75,500	19,634	.1264	--	316
40C12	4.019	1.259	76,375	19,003	.0540	--	
40C13	4.047	1.247	78,250	19,334	.1283	--	
			Average	19,484	.1274	-1.56	

40°C SPECIMENS (72 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
40C21	4.037	1.240	81,000	20,062	.1452	--	457
40C22	4.033	1.258	82,125	20,362	.1749	--	
40C23	4.039	1.235	78,625	19,464	.1134	--	
			Average	19,962	.1445	0.86	

40°C SPECIMENS (120 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
40C31	4.017	1.263	82,750	20,598	.1504	--	233
40C32	4.013	1.250	80,875	20,153	.1520	--	
40C33	4.037	1.264	82,750	20,496	.1503	--	
			Average	20,416	.1509	3.15	

Figure 25. Ultimate Strength Table for Control 3 and 40°C Specimens

55

100°C SPECIMENS (6 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
100C11	4.043	1.232	91,875	22,726	.1380	--	
100C12	4.011	1.251	93,000	23,189	.1359	--	360
100C13	3.887	1.231	87,375	22,481	.1219	--	
Average				22,799	.1319	15.19	

100°C SPECIMENS (18 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
100C21	3.842	1.257	91,500	23,818	.1750	--	
100C22	3.914	1.241	95,500	24,398	.1612	--	314
100C23	3.896	1.250	94,750	24,318	.1680	--	
Average				24,178	.1681	22.16	

100°C SPECIMENS (36 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
100C31	3.977	1.249	95,250	23,948	.1601	--	
100C32	3.879	1.255	93,250	24,041	.1594	--	117
100C33	3.890	1.256	92,625	23,809	.1513	--	
Average				23,933	.1569	20.92	

100°C SPECIMENS (48 HRS)

Specimen	Bearing Surface (in²)	Thickness (in²)	Maximum Force (lbf)	Ultimate Strength (psi)	Strain (in/in)	Strength Increase(%)	Strength Std Dev(psi)
100C41	3.865	1.265	92,125	23,835	.1423	--	
100C42	3.888	1.265	93,500	24,045	.1502	--	289
100C43	3.855	1.250	90,500	23,473	.1360	--	
Average				23,784	.1428	20.17	

Figure 26. Ultimate Strength Table for 100° C Specimens

ULTIMATE STRESS VS TEMPERATURE

LEGEND
□ = CONTROL
O = 24 HRS AT 40C
△ = 24 HRS AT 80C
+ = 24 HRS AT 120C
X = 24 HRS AT 160C
◇ = 24 HRS AT 200C

TEMPERATURE <DEGREES CELCIUS>
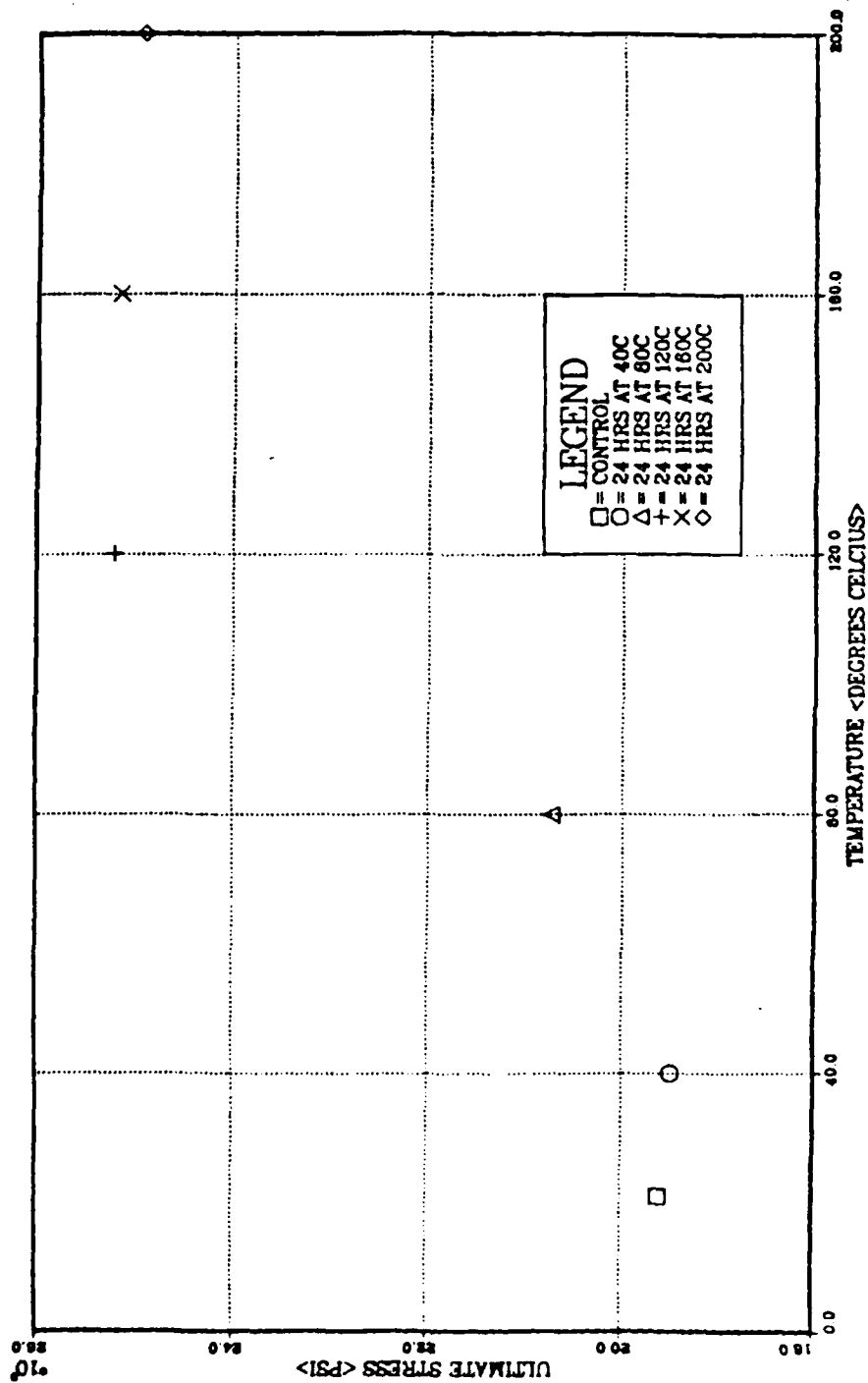
ULTIMATE STRESS <PSI>

Figure 27. Ultimate Strength vs. Temperature at 24 Hours

57

ESN3dX3 TN3WNЯ3ΛOƆ TV Q3ƆUQOЯd3Я
REPRODUCED AT GOVERNMENT EXPENSE
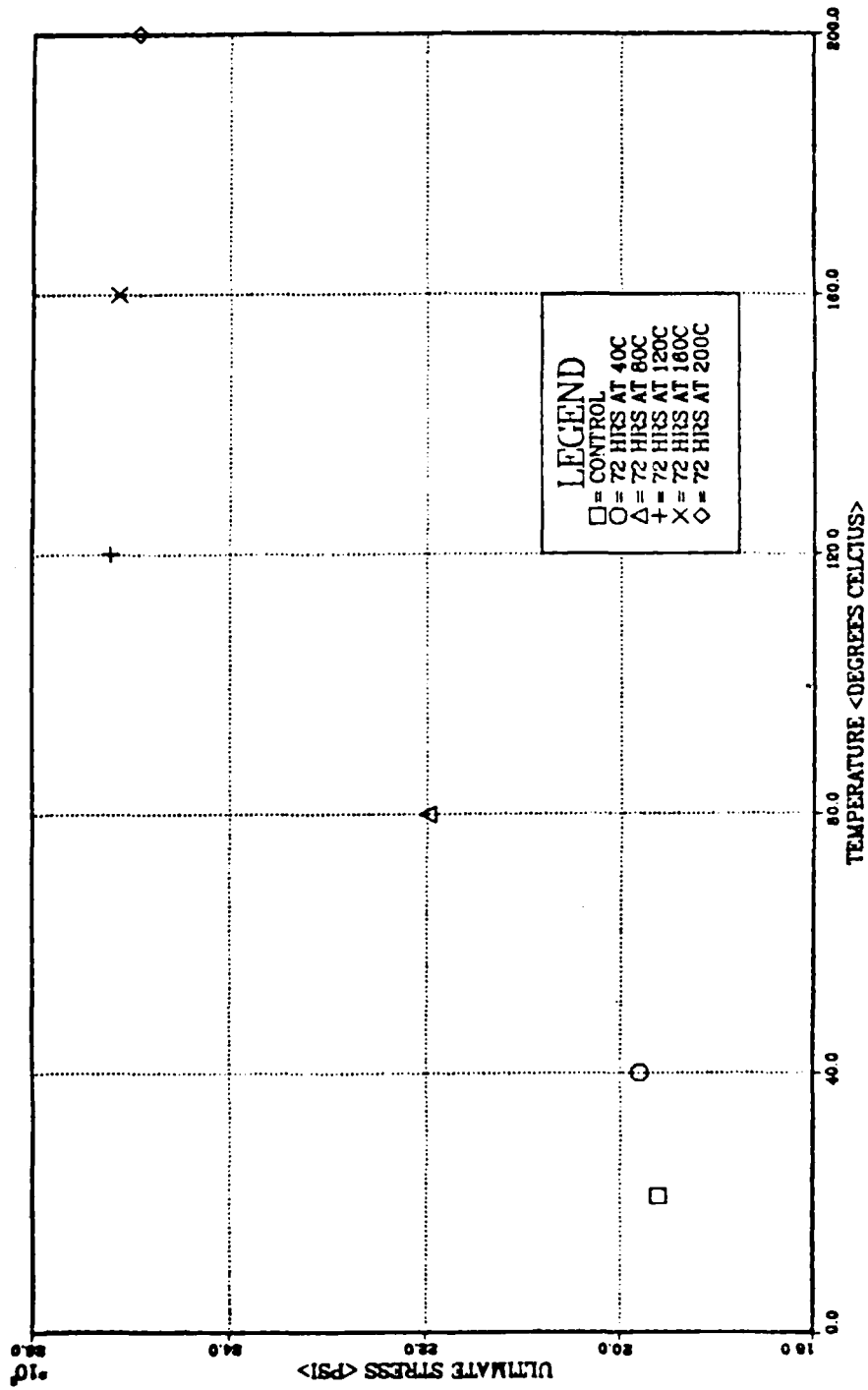
Figure 28. Ultimate Strength vs. Temperature at 72 Hours
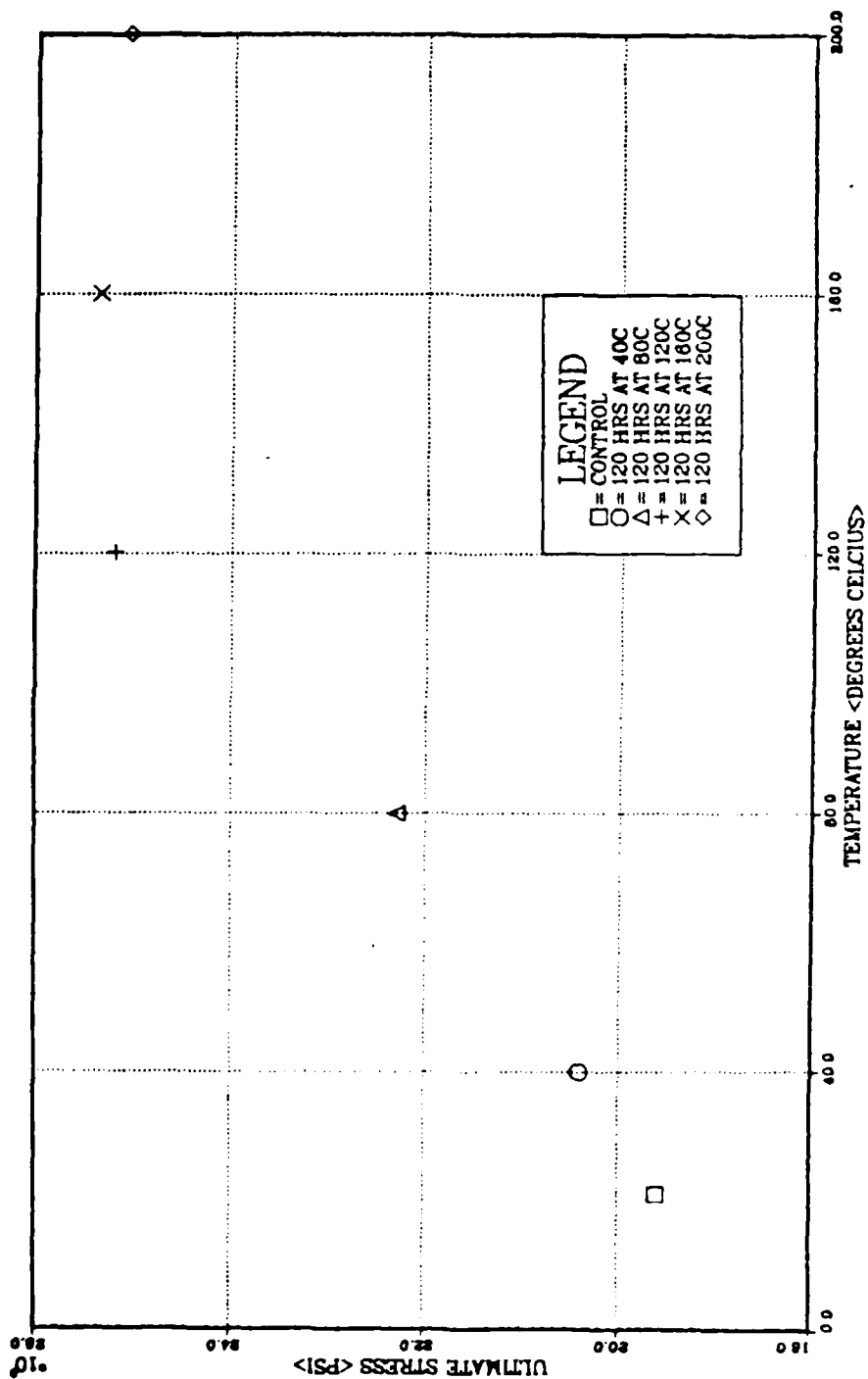
58

Figure 29. Ultimate Strength vs. Temperature at 120 Hours

59

CONTROL 1 VS 80C EXPOSURE

Figure 30. Control 1 vs. 80°C Exposure
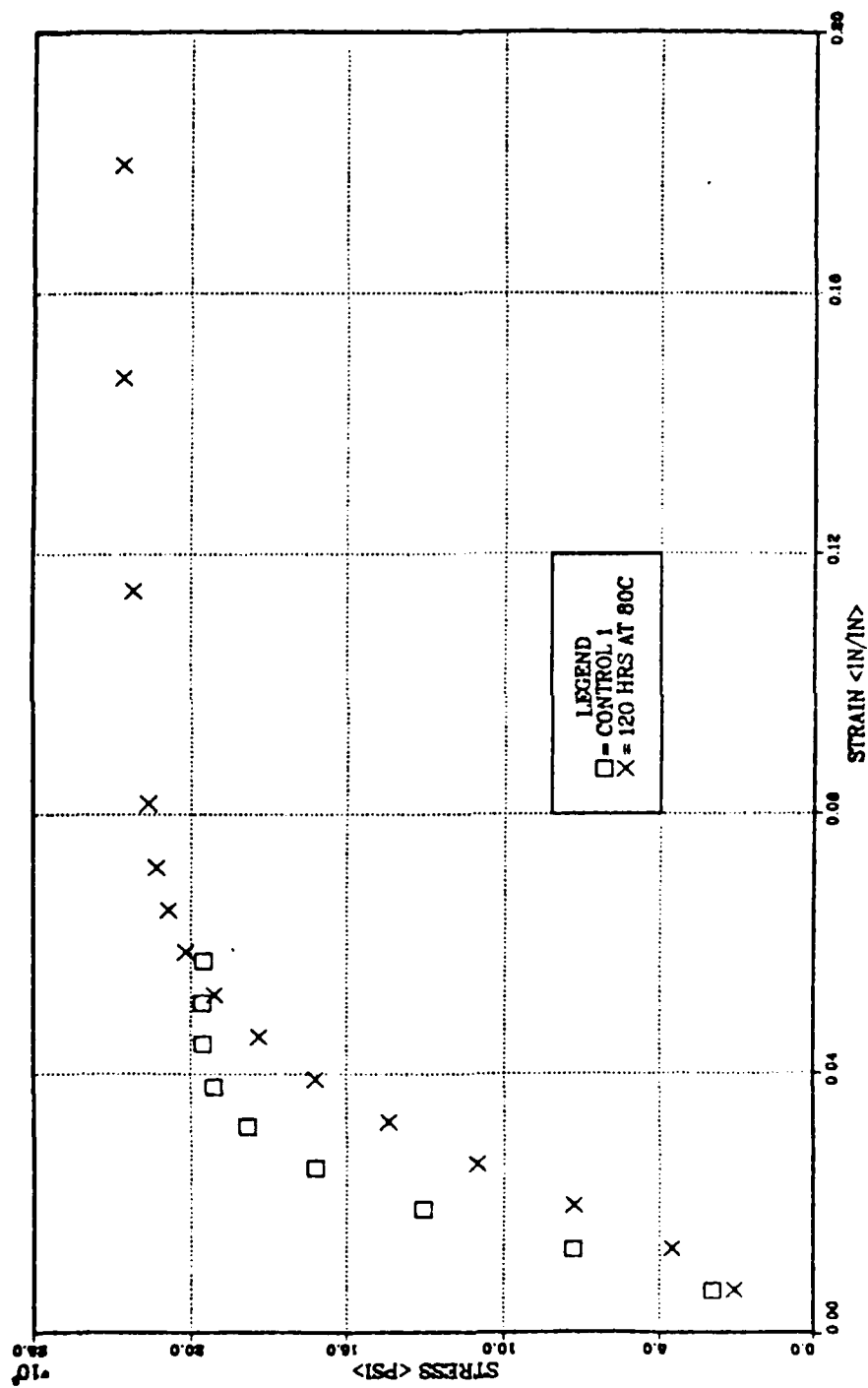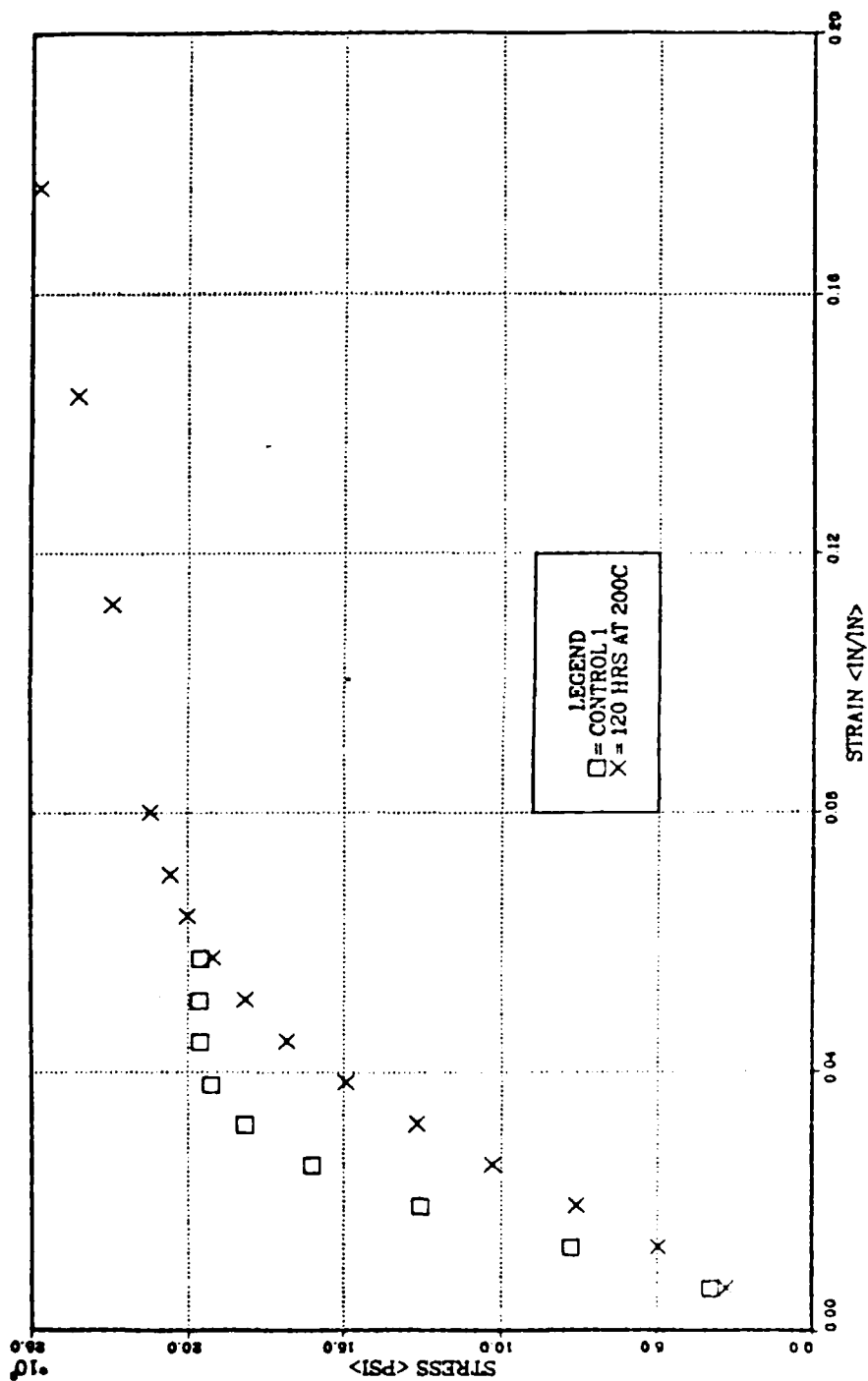
60

CONTROL 1 VS 200C EXPOSURE

Figure 31. Control 1 vs. 200°C Exposure

61

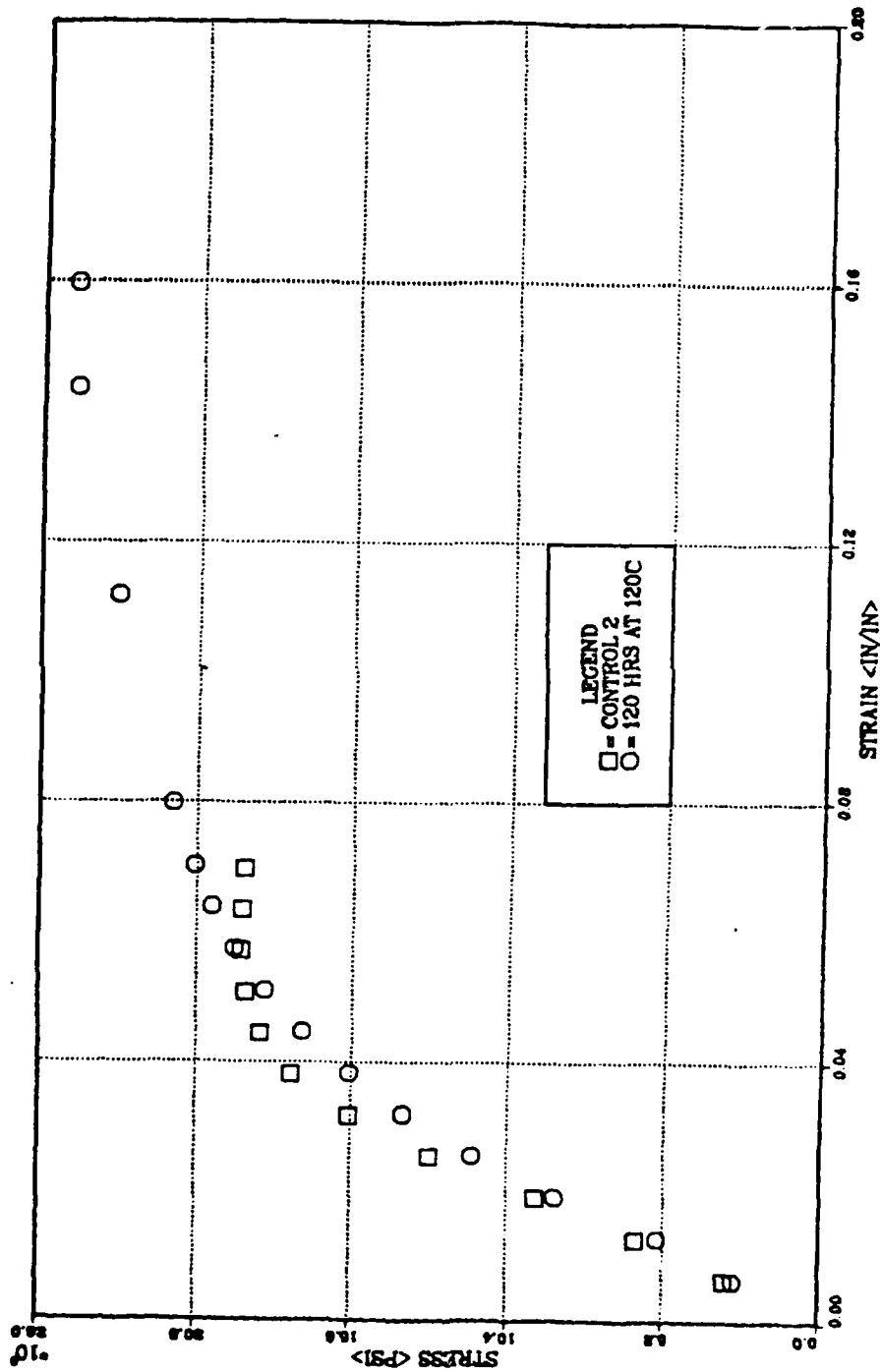# CONTROL 2 VS 120C EXPOSURE

Figure 32. Control 2 vs. 120°C Exposure
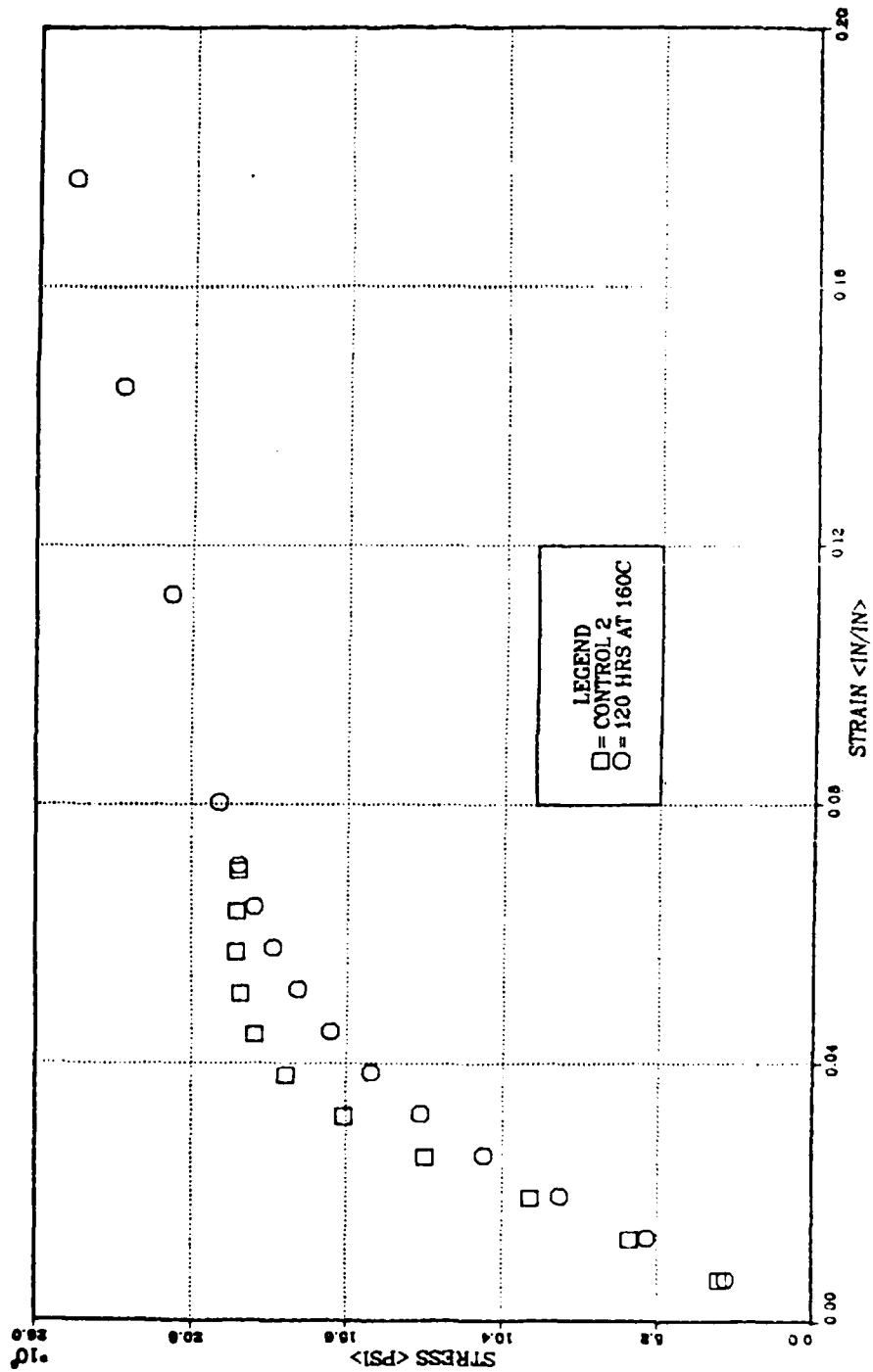
62

CONTROL 2 VS 160C EXPOSURE

Figure 33. Control 2 vs. 160°C Exposure

63

CONTROL 3 VS 40C EXPOSURE
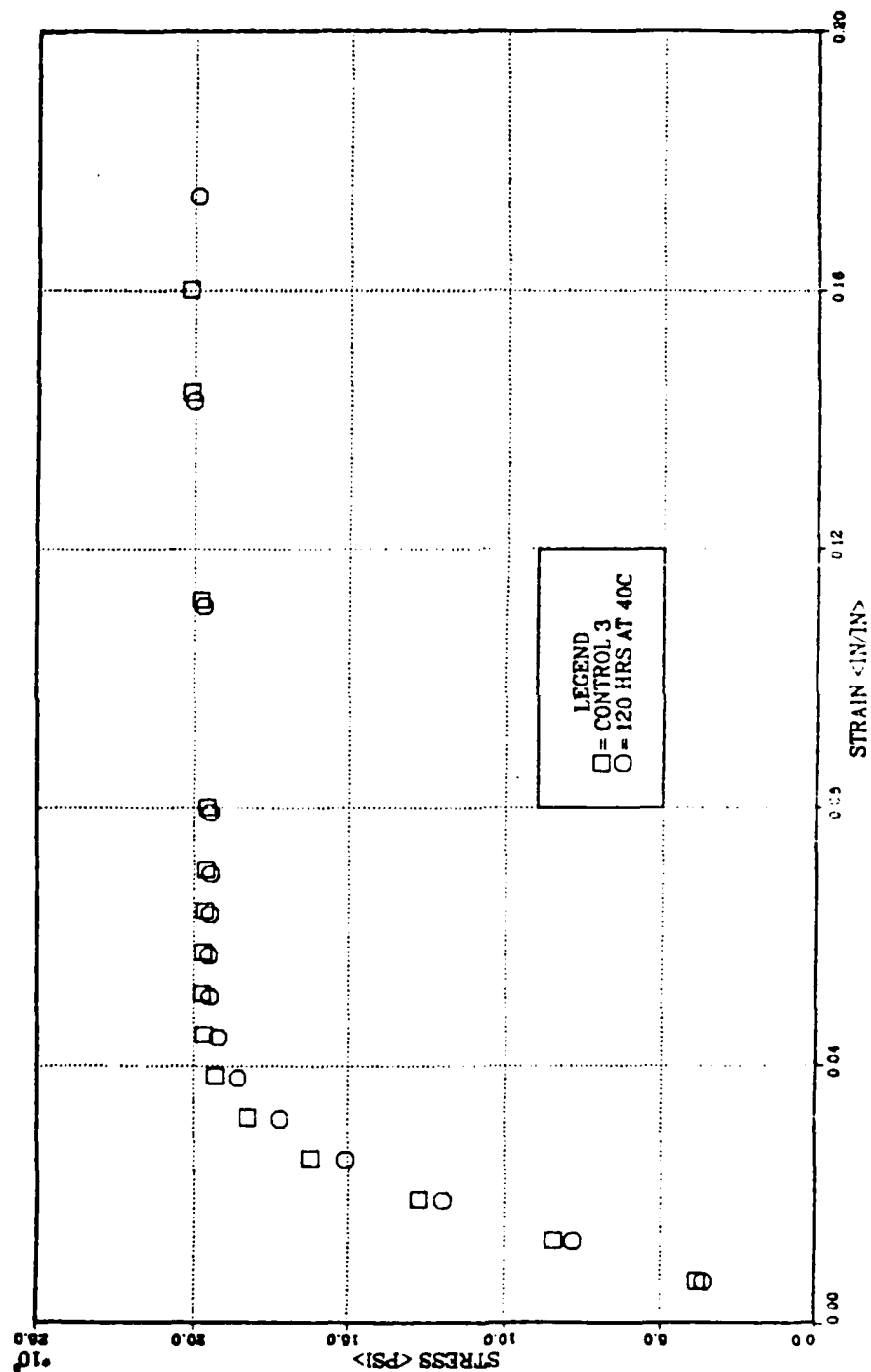
Figure 34. Control 3 vs. 40°C Exposure

64

CONTROL 3 VS 100C EXPOSURE
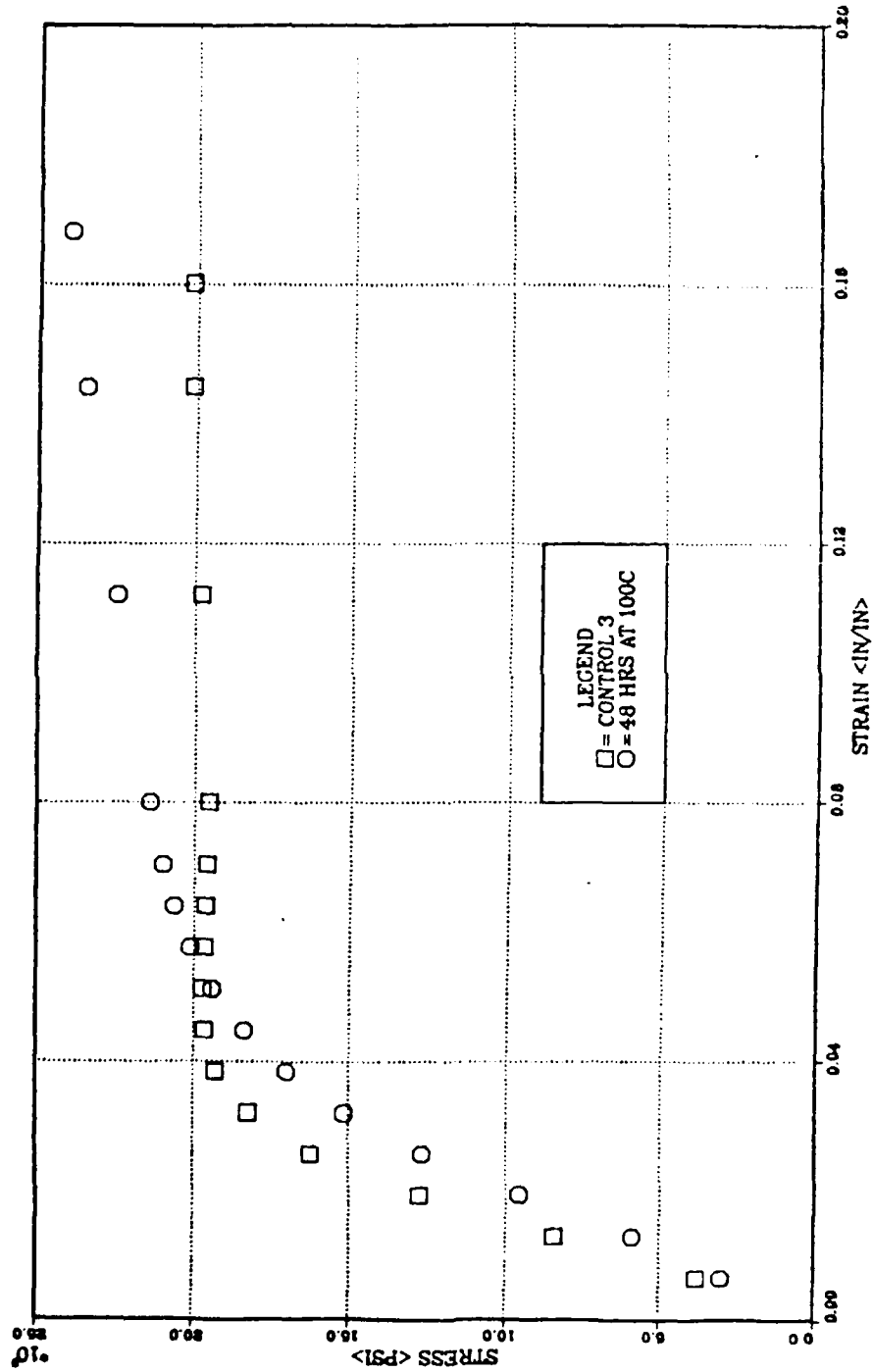
Figure 35. Control 3 vs. 100°C Exposure

65

Pour	Temperature	Exposure (Hrs)	σ_{ys} (psi)	E(psi)
	*21.5oC			
	(Control 1)	--	18,200	625,000
1	80°C	120	17,800	405,000
	200°C	120	16,900	390,000
	*21.5°C			
	(Control 2)	--	18,400	506,000
2	120°C	120	16,600	438,000
	160°C	120	14,000	419,000
	*21.5°C			
	(Control 3)	--	17,500	651,000
3	40°C	120	16,200	625,000
	100°C	48	15,800	588,000

* Due to the variation of the elastic modulus between the three control sets used in this experiment, the establishment of a trend is best recognized by a comparison of a particular control with its two associated elevated temperature groups.

Figure 36.   Tabulated Values of Yield Strength and Elastic Modulus

between the fully elastic and the fully plastic phases of compression the 0.2% offset method was used to determine the materials compressive yield strength while the elastic modulus for each chock set was obtained from the elastic portion of the stress versus strain curve [Ref. 15]. The elastic modulus from each of the three controls used in this experiment varied from 625,000 psi to 506,000 psi and finally 650,000 psi. This rather significant difference was overcome by avoiding cross comparison and relating only the stress versus strain response curves of each elevated temperature group to it's separate and distinct control. This analysis clearly brings out the decline in the material's stiffness with the effect being dependent on both temperature and time of exposure.

The material's elevated temperature compressive yield strength as calculated by the 0.2% offset method never exceeded the strength of it's respective control. In all cases the material's rigidity in the elastic phase of compressive deformation decreased with elevated temperature exposure.

67

X. CONCLUSIONS

The use of a full reduction of hardener in the mixing
process has minimal effect on the ultimate compressive
strength of the molded chocks. This is evidenced by the
close agreement between the control chock average ultimate
stength of 19,600 psi with the tabulated ASTM value of
19,000 psi. Further reinforcement is gained by examination
of the average control chock elastic modulus of 590,000 psi
as compared with the ASTM tabulated value of 550,000 psi
[Ref. 16].

The effects of enblock mold casting in lieu of
individual molds to produce the experimental chocks appeared
to be minimal. Cut specimens from the same enblock bar
displayed similar compressive characteristics. The original
concern over the development of internal mold hot spots
which would promote different curing rates within the
enblock epoxy resin bar was alleviated by the full reduction
of hardener and the insulation effect provided by the
silicon RTV mold. This permitted a consistently slow
cooling rate and developed a uniform temperature distribu-
tion throughout the enblock epoxy resin bar. The only
exception to this was at the exposed open end of the mold
which promoted a faster localized cooling rate and a small
section of uneven temperature distribution.

68

The entrapment of air bubbles within the chock specimens could not be avoided in the pouring of the enblock epoxy bars. During several of the compressive load tests abrupt fracture was observed to occur at much lower than average load levels. Examination of these specimens usually revealed that the fracture initiation site originated at an external air bubble which acted as a stress riser. These chocks were discarded from the experimental evaluation in accordance with the ASTM D 695 standards for compressive loading of rigid plastics. This practice helped to nullify the major adverse effect of entrapped air bubbles within the specimens.

The cutting of epoxy resin bars into the individual chock specimens had minimal effect on the compressive properties of the compound. The use of a diamond tipped radial saw blade with water cooling provided an efficient means of producing the 2" x 2" x 1 1/4" chocks without creating a heat effected zone on each specimen. Further, this was the cutting technique recommended by the manufacturer so as not to build up a pre-existing internal stress within each chock.

The reason for variation in the control chock elastic modulus as experienced between the three pours was not determined. A possible explanation for this could be attributed, however, to small differences in the amount of

69

hardener added to each can of CHOCKFAST ORANGE. In all
three cases, consistent preparation, mixing, and pouring
measures were followed in accordance with the manufacturer's
specifications. External temperature and humidity were
monitored and fell consistently within the established
limitations. The in mold cure time in each case was held to
48 hours. The evaluation of experimental results was not
hampered by the control modulus variation in that each set
of control chocks was compared with it's two associated
elevated temperature groups. If this practice had not been
maintained the analysis of data would have been signifi-
cantly more difficult.

The ultimate compressive strength of the 2" x 2" x 1 1/4"
epoxy resin chocks was increased by elevated temperature
exposure. This increase was a function of both temperature
and exposure time. The ultimate stress for each exposure
time underwent a transition of slight to moderate escalation
between the ambient and 80°C temperatures with a significant
increase realized in the 80°C to 120°C range and a consis-
tent but slowly declining curve observed for the 120°C to
200°C interval. A maximum increase of approximately 30%
over the respective controls was realized for the 120°C,
160°C, and 200°C specimens. The ultimate strengths for
the elevated groups were achieved in much less time for
the higher temperatures as opposed to the 40°C and 80°C

70

temperatures which potentially display an increasing trend through the maximum exposure duration of 120 hours.

The elevated temperature exposure of the epoxy resin chocks caused a decrease in the elastic modulus of the material as compared with each group's respective control. The maximum change in stiffness varied both with time and temperature. The maximum deviation for the lower temperatures of $40^{\circ}C$ and $80^{\circ}C$ occurred at the 120 hour exposure time. The upper temperatures of $120^{\circ}C$, $160^{\circ}C$, and $200^{\circ}C$ showed maximum deviation of the elastic modulus occurring primarily at the 24 hour exposure with a slight tendency to regain some stiffness at the 72 and 120 hour marks. The $100^{\circ}C$ temperature exposure was conducted at 6, 18, 36, and 48 hour intervals of chock removal so as to explore the sensitive temperature zone occurring between the $80^{\circ}C$ and $120^{\circ}C$ temperatures. The greatest deviation in the elastic modulus was observed at the 18 hour interval with the chocks displaying a small tendency to regain stiffness at the 36 and 48 hour marks.

The compressive yield strength for the maximum duration exposure of the epoxy resin chocks as calculated by the 0.2% offset method [Ref. 17] decreased in all cases. The effect of elevated temperature exposure on the compressive yield strengths of the experimental chocks varied both with time and temperature. The offset method employed for this

71

calculation is understandably dependent on the materials elastic to plastic transition. The variables of time and temperature caused changes in the initial slope of the stress strain curve thus having a strong influence on the resulting yield strength.

The current application of CHOCKFAST ORANGE by the Navy limits the static loading of this material to 1000 psi for regular equipment installations and 500 psi for machinery installations requiring careful alignment [Ref. 18]. Although the use of CHOCKFAST ORANGE in a shipboard environment involves significant dynamic effects from the normal roll, pitch, and yaw motions as well as machinery and equipment vibration, the material is not being utilized to anywhere near its available strength. This is clearly indicated from the yield strengths calculated in this study. A safety factor of approximately 15 to 20 is currently being employed for most applications of CHOCKFAST ORANGE on naval vessels.

The effect of an increase in ultimate strength was overshadowed by the resulting decline in both yield strength and elastic modulus. The properties of a high yield strength and a strong elastic modulus are important in the alignment of heavy machinery aboard vessels. The use of heat treatment after pouring but before full torque down of the machinery mounting bolts is not desirable, as determined from the exposure times selected in this study.

72

LIST OF REFERENCES

1. Advanced Marine Enterprises, Inc., <u>State-of-the-Art</u>
    <u>Summary for Epoxy Resins Chocks</u>, pp. 3-1 through 3-3,
    1982.

2. Ibid., pp. 1-1 through 1-5.

3. Ibid., p. 1-1.

4. Lee, H. and Nelville, K., <u>Handbook of Epoxy Resins</u>,
    p. 1-1, McGraw-Hill, 1967.

5. Ibid., p. 1-2.

6. Ibid., pp. 1-4 through 1-7.

7. Ibid., p. 2-3.

8. Ibid., p. 2-4.

9. Ibid., pp. 2-3 and 2-4.

10. Ibid., p. 5-1.

11. Ibid., p. 5-3.

12. Advanced Marine Enterprises, Inc., <u>State-of-the-Art</u>
    <u>Summary for Epoxy Resin Chocks</u>, p. 4-3, 1982.

13. Philadelphia Resins Corporation Technical Bulletin No.
    654, <u>CHOCKFAST Application Instructions</u>, 1980.

14. Philadelphia Resins Corporation Technical Bulletin No.
    652A, <u>CHOCKFAST Guidelines for Marine Designers</u>, 1980.

15. Bauld, Jr., N. R., <u>Mechanics of Materials</u>, Brooks/Cole
    Engineering Division, pp. 30-32, 1982.

16. Advanced Marine Enterprises, Inc., <u>State-of-the-Art</u>
    <u>Summary for Epoxy Resin Chocks</u>, p. 4-3, 1982.

17. Bauld, Jr., N.R., <u>Mechanics of Materials</u>, Brooks/Cole
    Engineering Division, pp. 30-32, 1982.

18. Advanced Marine Enterprises, Inc., <u>State-of-the-Art</u>
    <u>Summary for Epoxy Resin Chocks</u>, p. 1-3, 1982.

INITIAL DISTRIBUTION LIST

                                                              No. Copies

1.   Defense Technical Information Center   2
     Cameron Station
     Alexandria, VA   22314

2.   Library, Code 0142   2
     Naval Postgraduate School
     Monterey, CA   93943

3.   Professor Paul Marto, Code 69Mx   1
     Chairman, Department of Mechanical
          Engineering
     Naval Postgraduate School
     Monterey, CA   93943

4.   Professor David Salinas, Code 69Zc   2
     Naval Postgraduate School
     Monterey, CA   93943

5.   Commandant (G-PTE)   2
     U.S. Coast Guard
     Washington, D.C.   20590

6.   Naval Sea Systems Command   2
     Department of the Navy
     Code 55Y3
     Attn: Mr. William Siekierka
     Washington, D.C.   20362

7.   David Taylor Naval Ship R and D Center   1
     Code 1730.2
     Attn: Mr. Ron Purcell
     Bethesda, MD   20084

8.   David Taylor Naval Ship R and D Center   1
     Code 1211
     Attn: Mr. Owen Ritter
     Bethesda, MD   20084

9.   LT Richard Prince   1
     MMT
     Eighth Coast Guard District
     Hale Boggs Federal Bldg.
     500 Camp Street
     New Orleans, LA   70130

74

END

FILMED

5-85

DTIC